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AN EXAMINATION OF THE ADVANCED COMMUNICATIONS TECHNOLOGY SATELLITE (ACTS) AND ITS APPLICATION TO THE DEFENSE DATA NETWORK (DDN)

by

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This thesis examines NASA's Advanced Communications Technology Satellite (ACTS) with emphasis on its potential applicability to the Defense Data Network (DDN). The ACTS program is a joint NASA industry program to develop the next generation of communications satellites, thus assuring the U.S.'s continued pre-eminence in this area. The ACTS will essentially operate as a "switchboard in the sky." The thrust of the thesis is to take a broad-brush look at the system and discuss its applicability to DoD's packet switching data network, the DDN. This thesis is written so that a technical background is not required by the reader. Applicable background information is provided where necessary. The emphasis is on the concepts involved and a discussion of the interoperability of the two systems.

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An Examination of the Advanced Communications Technology Satellite (ACTS) and its Application to the Defense Data Network (DDN)

by

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Submitted in partial fulfillment of the
requirements for the degree of

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ABSTRACT

This thesis examines NASA's Advanced Communications Technology Satellite (ACTS) with emphasis on its potential applicability to the Defense Data Network (DDN). The ACTS program is a joint NASA industry program to develop the next generation of communications satellites, thus assuring the U.S.'s continued pre-eminence in this area. The ACTS will essentially operate as a "switchboard in the sky." The thrust of the thesis is to take a broad-brush look at the system and discuss its applicability to DoD's packet switching data network, the DDN. This thesis is written so that a technical background is not required by the reader. Applicable background information is provided where necessary. The emphasis is on the concepts involved and a discussion of the interoperability of the two systems.

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I. INTRODUCTION

A. A CHANGING COMMUNICATIONS ENVIRONMENT

The communications field has always functioned within a rapidly changing environment. In the relatively short period since the early part of this century, the communications field has moved from wire line telephones and radio broadcasts to today's world of global live television, wireless telephones, cellular telephones, computing from home, and local area computer networks. The technological progress continues as use of light as a communications medium and other capabilities, such as video telephone calls start to emerge. These advances have been made possible through the rapid expansion of technology in computers, integrated circuits, communications equipment and the use of space.

The use of space is highlighted because without the contribution of the numerous communications satellites circling the globe today the extensive capabilities of the television and communications industry would not be possible. It is, therefore, advisable that when a major force impacts on this very important area one should take note of the fact and observe the reaction. The major force, in this case, is the emergence of fiber optics in the commercial industry marketplace as a competitor for the communications traffic carried by satellites. The reaction from the communications satellite industry has been to perform a comprehensive evaluation of the satellite's role in meeting future communications needs. The product of this evaluation will incorporate state-of-the-art communications technology and the unique advantages of satellite communications. The objective will be to provide the commercial satellite industry a new and dynamic system that is competitive in the communications marketplace. The military, as a major user of satellites, both military and commercial, for communications purposes, will be affected by this evolution of satellite use and must be prepared for its onset. This evolution of satellite technology is being spearheaded by the National Aeronautics and Space Administration (NASA) and the communications satellite industry. This joint development effort has

been designated the Advanced Communications Technology Satellite (ACTS). This thesis will delve into this currently emerging area of satellite communications.

B. OBJECTIVES

The primary objective of this thesis is to examine the NASA-industry communications development program, the ACTS program, and its possible application to the Defense Data Network (DDN). The secondary objective is to provide the reader current information on areas associated with the primary objective to support further studies of related issues.

C. SCOPE

This thesis will focus on the concepts involved in the NASA-industry program and its applications to the DDN. The thrust of this effort is a broad discussion of the pertinent systems and concepts and not a detailed examination of the technology or communications concepts involved. Detailed information may be provided to the reader as background information or to support the understanding of other concepts. By focusing on a more general discussion it is intended that the information assembled, its subsequent discussion, and the conclusions drawn will lead to further more detailed studies in this area.

This thesis will not attempt to determine or comment on the feasibility or appropriateness of the ACTS program in general. The ACTS program exists as an active program within NASA, and the information provided describes that program. For discussion purposes within this thesis, information referenced from sources which may be viewed as biased toward the program will be accepted. A more detailed look at the subject area may require a more comparative analysis to determine the validity of this information. As a final note, it should be remembered that the ACTS program is an experimental program and some assumptions made or conclusions drawn by some sources may be changed as a result of further evaluation of the system.

D. ORGANIZATION OF STUDY

The succeeding chapters will examine those areas that will provide the information needed to discuss the application of the NASA-industry program to the DDN. The first two chapters will provide an overview of the commercial satellite industry. The emphasis in the first chapter is on the evolution of current satellite systems. It also provides some background information related to space communications systems. The second chapter looks at tomorrow's outlook for the communications satellite with emphasis on the NASA-industry ACTS program. After this overview of commercial satellites, an overview of the DDN follows in the next chapter. This provides a broad look at the DDN's evolution, components, and operation. Chapter V discusses the application of the ACTS system to the DDN. Finally, Chapter VI highlights the conclusions reached in the thesis and outlines areas for further study.

II. COMMERCIAL SATELLITE COMMUNICATIONS--TODAY

To understand where commercial satellite communications is going it is important to understand how it got where it is. This chapter will briefly examine the evolution of satellite communications from the beginning to today and how the emergence of fiber optics has affected the satellite role. However, before examining these areas, it is important for the reader to understand a few basics about satellite orbits and satellite communications engineering concepts.

A. A FEW BASICS

The intent of this section is not to go into detail about orbital mechanics or communications engineering. The focus is to briefly discuss those main points that will allow the reader to gather the maximum benefit from information presented throughout this thesis. In later chapters these topic areas will be expanded where necessary to provide further information in specific areas.

1. Communications Satellite Orbits

The importance of satellites as communications platforms is readily apparent by examining the simple illustration at Figure 2.1. In Figure 2.1a, the path between two of the transmitting/receiving stations is approximately 30 miles. This path, known generally as the radio line of sight (LOS), is directly determined by the curvature of the earth. Of course, buildings, mountains or other obstructions can affect the radio LOS, making it longer or shorter, but a ground to ground clear path between two points is approximately 30 miles [Ref. 1: p. 2]. Therefore, a telephone call between Los Angeles and New York would have to cross many such systems to complete the circuit. It is apparent from further study of Figure 2.1a that as either station, or both, are further elevated the maximum radio LOS distance between the two stations increases. This simple concept is the basis

for the importance of today's communications satellites, as illustrated in Figure 2.1b.

As stated, the height of the receiving/transmitting or relay station directly affects the possible LOS distance between two end stations. The construction of immense towers, or the use of balloons or aircraft were not feasible long term answers. The answer was a platform that maintained a required altitude without continuous adjustment or power requirement (for instance, jet engines). A satellite in orbit was looked to as an effective solution to the problem. However, using the satellite as a communications platform subjects it to the same laws of nature and forces that affect the moon as a satellite of the earth and the Earth as a satellite of the sun. While not delving deeply into the mechanics of satellite orbits, suffice it to say that there are almost an infinite number of orbits available to a satellite, but communications considerations limit the usable choices to a relative few.

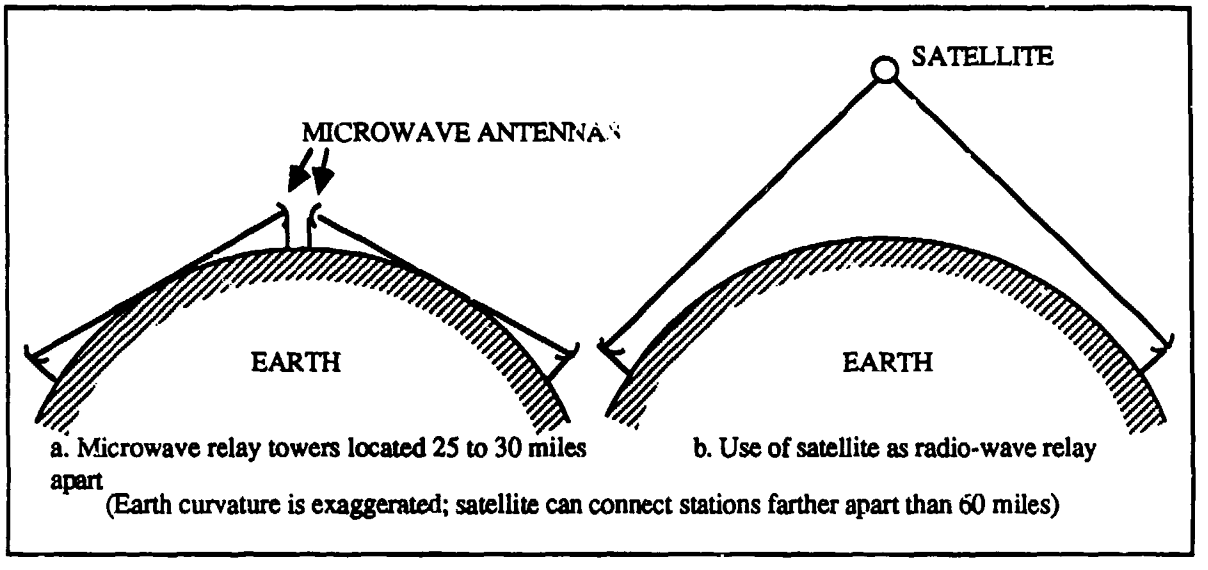


Figure 2.1 Satellite vs. Ground Systems [Ref. 1: p. 2]

A basic statement of the orbital mechanics involved with satellites is that the closer they are to the earth, the smaller their time to orbit the earth, called their orbital period. Table 2.1 shows some examples of orbital periods for various circular orbits. The orbital period is a key consideration in the engineering of satellite communications systems. From Table 2.1, a satellite

at 1000 miles above the earth will orbit the earth approximately 12 times in a twenty-four hour period. This is not ideal for most applications of communications satellites because of the loss of signal as the satellite passes out of the LOS of ground stations and the delay until contact is reestablished on the next orbit. Additionally, if multiple satellites are used to insure connectivity, the requirement to *hand off* the communications signal from satellite to satellite increases the complexity and cost of the system.

TABLE 2.1 CIRCULAR ORBITAL VELOCITIES AND ORBITAL PERIODS FOR EARTH SATELLITES AT VARIOUS ALTITUDES [Ref. 1: p.52]

ALTITUDE		VELOCITY		PERIOD
KILOMETERS	MILES	KILOMETERS PER SECOND	MILES PER SECOND	
0	0	7.91	4.92	1 h 24.3 min
161	100	7.80	4.85	1 h 27.7 min
322	200	7.70	4.79	1 h 30.8 min
644	400	7.53	4.68	1 h 37.5 min
1609	1000	7.06	4.39	1 h 57.7 min
8045	5000	5.26	3.27	4 h 46.6 min
35,880	22,300	3.07	1.91	24 h

However, if the satellite is moved out to an altitude of approximately 22,300 miles, the orbital period of the satellite becomes 24 hours (Table 2.1). Now the satellite has an orbital period that corresponds to the period of the earth's rotation. This is called a geosynchronous orbit. A variation of the geosynchronous orbit is called a geostationary orbit both will be further described in the following paragraphs. These orbits greatly simplify the engineering aspects of the communications system. This is not to say that other orbits are not used for communications. However, by far most communications satellites in use today are in a geosynchronous orbit. Orbits at lower altitudes are generally used for reconnaissance, navigation, surveillance, land/ocean resources, or meteorological satellites.

The orbital altitude is one factor impacting orbit selection for communications satellites. The second factor is orbital inclination. The

orbital inclination is the angle formed by the intersection of the plane of the orbit with the plane passing through the earth's equator. Figure 2.2 shows an example of this concept. The importance of the orbital inclination will be discussed only with respect to geosynchronous satellites.

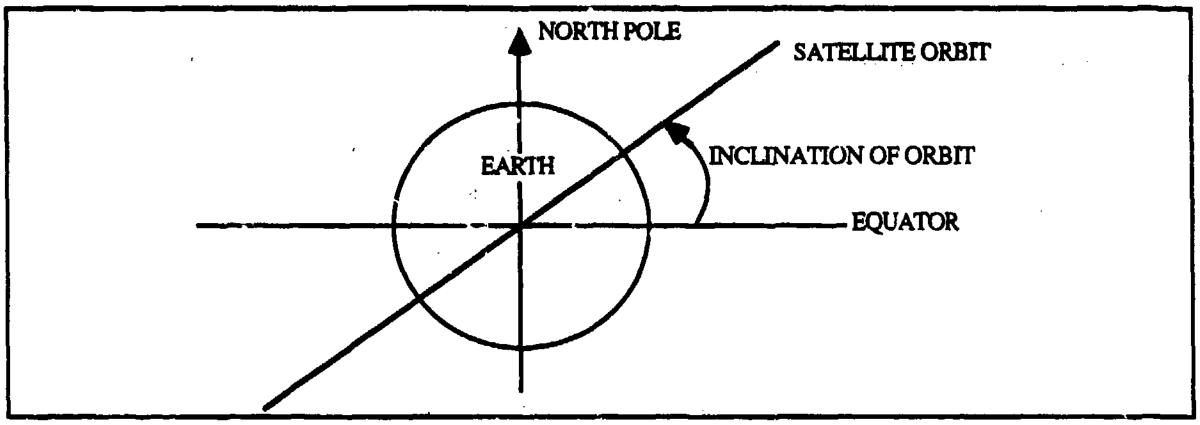


Figure 2.2 Orbital Inclination (Edge View of Orbit)

The earth is not a perfectly round ball , rather, it *bulges* around the equator. This *bulge* of the earth causes perturbations in the orbits of all satellites about the earth as a result of the variation in gravitational forces [Ref. 1: pp. 73-74]. For the geosynchronous orbit, the perturbations are as shown in Figure 2.3. The figure eight shown is the ground trace of the satellite path on the earth, or what is called the subsatellite point. The more inclined the orbit of the geosynchronous satellite the larger the figure eight. Therefore a geosynchronous orbit remains over a specific *area* on the earth depending on its orbital inclination. As the size of the figure eight increases, so does the complexity of ground operations to maintain satellite tracking and communications quality. Therefore, the object of most communications providers is to make the figure eight as small as possible. To negate the effect of the earth's *bulge* as much as possible, the inclination of the orbit must be zero. Therefore, the combination of these two factors, the altitude of the orbit (22258.94 mi) and its inclination (0°) provide the primary orbit for communications satellites about the earth. This orbit, because it has a 24 hour period, is geosynchronous. The fact that it also has zero degrees orbital inclination, or orbits the earth along the equator, makes

the orbit geostationary. A geostationary orbit remains over a specific *point* on the earth because it is at zero inclination. [Ref. 2: pp. 3-36, 3-40, 3-41]

The inherent stability of the geostationary orbit is not the only advantage gained from a communications perspective. From Figure 2.1, it was shown that to connect two distant points on the ground a relay was needed at a height where both stations would have LOS to the relay station. The higher the relay, or in this case the satellite, the farther the end points could be from each other. The geostationary satellite combines the advantage of being over the same point on the ground continuously with being able to

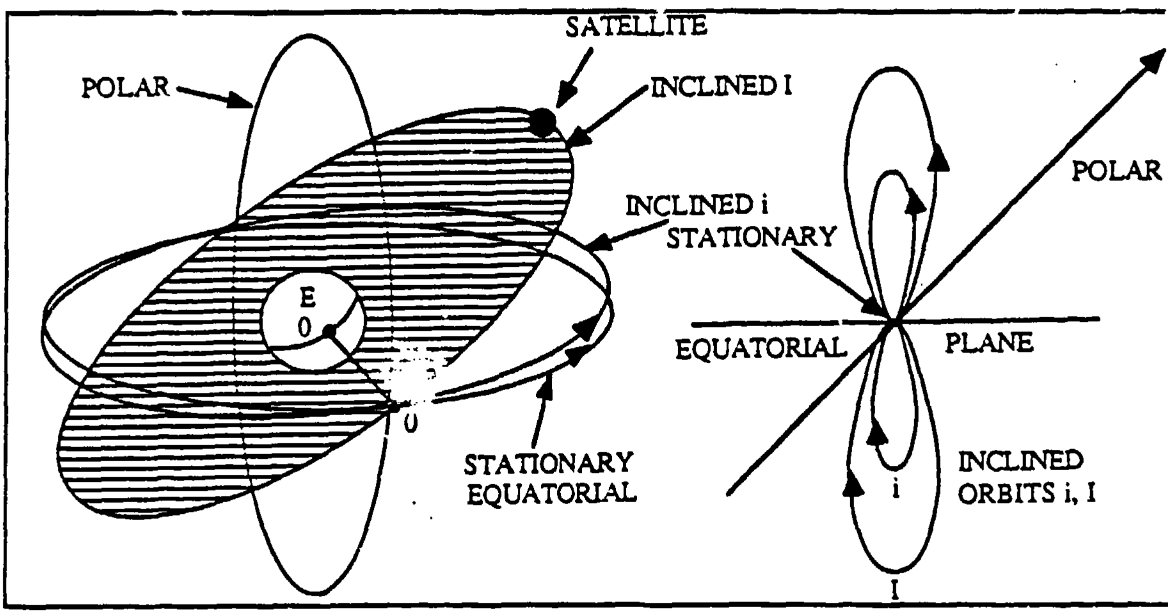


Figure 2.3 Earth Synchronous Orbits and the Figure Eight of the Subsatellite Point [Ref. 2: p. 3-43]

see an immense area on the ground. This area is known as the satellite's field of view (FOV). For a geostationary satellite it is approximately one-third of the earth's surface. Figure 2.4 shows the geometry of the geostationary orbit, highlighting the fact that a constellation of three satellites would provide coverage for almost the entire earth. The polar regions of the earth, shown as the shaded no coverage area in Figure 2.4, are affected by the curvature of the earth that blocks them from the satellite's fields of view.

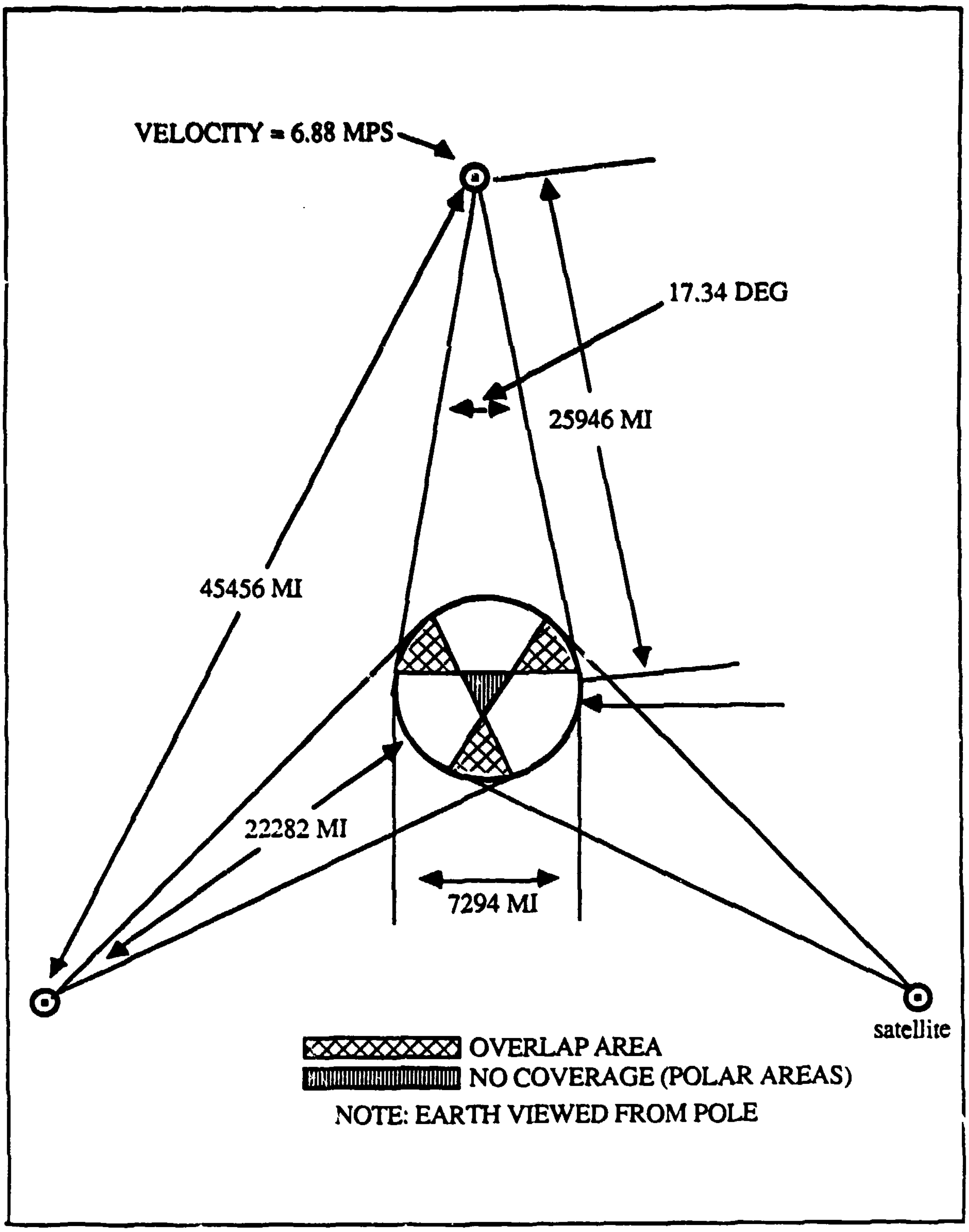
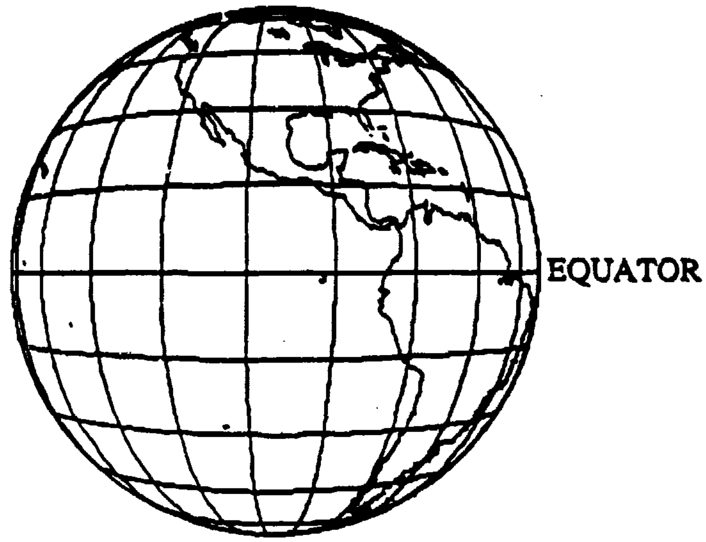


Figure 2.4 Geometry of Satellite Orbit [Ref. 2: p. 2-5]

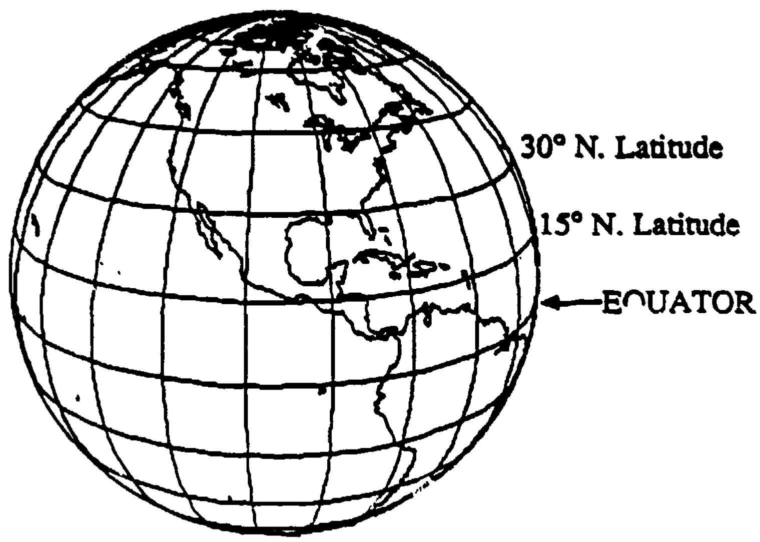
Figure 2.5a depicts what a satellite would *see* from approximately geostationary orbit (22,000 mi). Areas above 81.25° north and south are not seen [Ref. 2: p. 2-4]. The reader will notice from the figure that the two polar regions are not visible to the satellite. This is reinforced by examining Figure 2.5b, which shows a view of the earth from approximately geosynchronous orbit at an orbit inclination of 20° (20° North latitude). The polar area is clearly visible from this position. While most communications satellites use geostationary orbits, the requirements to provide service to areas not covered from that orbit may require the use of other orbits not discussed here.

2. Communications Engineering for Satellites

Communications engineering for satellites, like satellite orbits, has some basic concepts, terms, and realities that provide a foundation for understanding satellite systems. As described above, the satellite provides the capability to extend the range of communications systems without numerous system links. The satellite, in its most commonly used form, is a high altitude relay or repeater station. A commonly used expression for a satellite operating in this manner is *bent pipe* operation. The satellite merely receives the incoming electromagnetic radiation from the transmitting ground terminal and lets it *flow* through the *bent pipe* to the appropriate receiving ground terminal. Although essentially correct, the operation is not quite that simple. The energy transmitted from the ground station has diminished by the time it reaches the satellite due to path loss. The satellite must amplify the energy received prior to transmitting to the ground terminal to insure that the receive signal level at the ground terminal is sufficient to support communications. Additionally, to prevent interference and feedback at the satellite the frequency of the incoming signal must be changed prior to retransmission. Therefore, in addition to the reception and transmission of the signal, the relay satellite must first change the frequency and then amplify the signal prior to retransmission. The transmission of the downlink signal in response to an uplink signal is the function of a transponder. The number of transponders on satellites has increased with the advance of satellite technology thereby increasing communications capacity.



a. Earth View from Satellite in Geosynchronous
Orbit over the Equator (0° Latitude)



b. Earth View from Satellite in Geosynchronous
Orbit at 20° North Latitude

Figure 2.5 Earth Views

The basic ***bent pipe*** relay satellites are giving way to the more sophisticated processing satellites. A processing satellite acts upon the incoming signal, other than changing frequencies or amplification, prior to retransmission of the data. This may take the form of reformatting the data, switching the uplink data to different downlink paths depending on the destination of the signal or switching individual channels to different paths. The concept of a processing satellite will be more fully examined in Chapter III. [Ref. 3: p. 4]

To understand the importance of the satellite's communications area coverage to its mission and capabilities, a brief discussion of antenna basics is required. The antenna is basically an interface between the electronic circuit and the outside electromagnetic field. The antenna converts the current or voltage to electromagnetic waves at the transmitter and vice versa at the receiver. A key feature of an antenna is its radiation pattern. The radiation pattern is a representation of the intensity of the antenna radiation in a given plane. For example, Figure 2.6a shows the radiation plot for an omnidirectional antenna. Omnidirectional means that the relative strength of the antenna power density is constant at a given distance from the antenna in any direction. Figure 2.6b shows a more directional pattern with a major lobe towards the top of the page and several minor lobes around the bottom side. This indicates that the major power density is concentrated towards the top of the page. This pattern changes for different types of antennas. [Ref. 4: pp. 511-513]

A commonly used term when discussing antennas and a term which is important in engineering communications systems is antenna gain. The gain for a particular antenna is the ratio of the maximum power density of that antenna to the maximum power density of a reference antenna in a given direction (usually the max). For the most part, the reference antenna used is an isotropic point radiator (ISR), i.e., omnidirectional. The value for the ISR is determined by dividing the maximum power transmitted by the volume of a sphere with a radius that encloses the antenna. The gain of an antenna is normally expressed in decibels. Since the antenna is a passive device and does not create power, the term gain may be misleading Simply put, the power that is radiated in all directions, as an ISR represents, is shaped

and focused by the particular antenna. This increases the power radiated in a specific direction, thereby producing an effective gain of power in that direction. For an antenna of a given size the higher the operating frequencies the higher the gains that are practical. [Ref. 4: pp. 514-515]

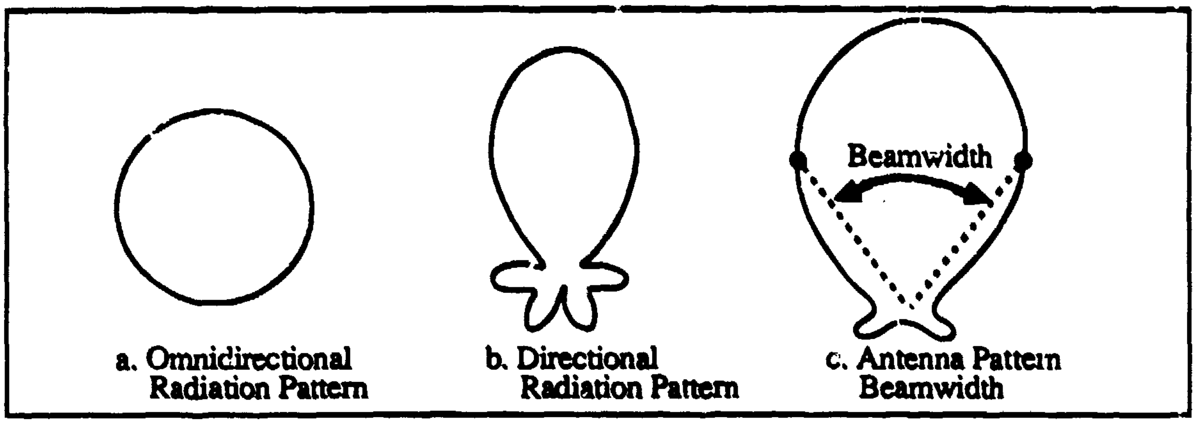


Figure 2.6 Antenna Radiation Pattern and Beamwidth [Ref. 4: pp. 513, 516]

A brief discussion of antenna beamwidth will close this detailed look at antennas. The beamwidth is defined as "the angular separation between the two half-power points (3dB down from maximum) of the radiation pattern in a given plane" [Ref. 4: p. 516]. Figure 2.6c shows a simple illustration of the beamwidth for a typical antenna power radiation pattern. A trade off exists between the beamwidth and the gain of the antenna. Antennas having a narrower beamwidth have greater gains and vice versa [Ref. 4: p. 516].

The altitude of the satellite is not the only factor in determining the communications coverage area of the satellite. The coverage area is heavily influenced by the capabilities of the communications systems aboard the spacecraft. Antennas that can cover the earth's surface as viewed from geostationary orbit are known as earth or global coverage antennas. This name is somewhat of a misnomer because the antennas only *see* about a third of the earth. They do not cover the polar areas and the actual antenna beam realistically covers an even smaller area [Ref. 2: p. 2-4].

As previously mentioned, the farthest north and south that a satellite can *see* from a geostationary position is 81.25°. At this latitude the

satellite would appear to be on the horizon to the satellite terminal. It is a general rule of thumb to not expect high performance from a terminal whose elevation angle to the satellite is less than 10° [Ref. 2: p. 2-4]. Figure 2.7(on page 24) outlines the actual coverage for a geostationary satellite at 30° West longitude. The contour line drawn for terminals with a 10° elevation angle shows that coverage is possible for close to one-third of the earth's circumference. However, in the vicinity of the 60° latitude lines the coverage area contracts due to the elliptical shape of the projected downlink pattern of the antenna beam. Although the pattern could be adjusted to account for the problem, the general rule of 10° elevation is still practical. To alleviate the problem, a four satellite constellation is used to provide the global coverage except for polar regions. An example of this is shown at Figure 2.8. [Ref. 2: p. 2-4]

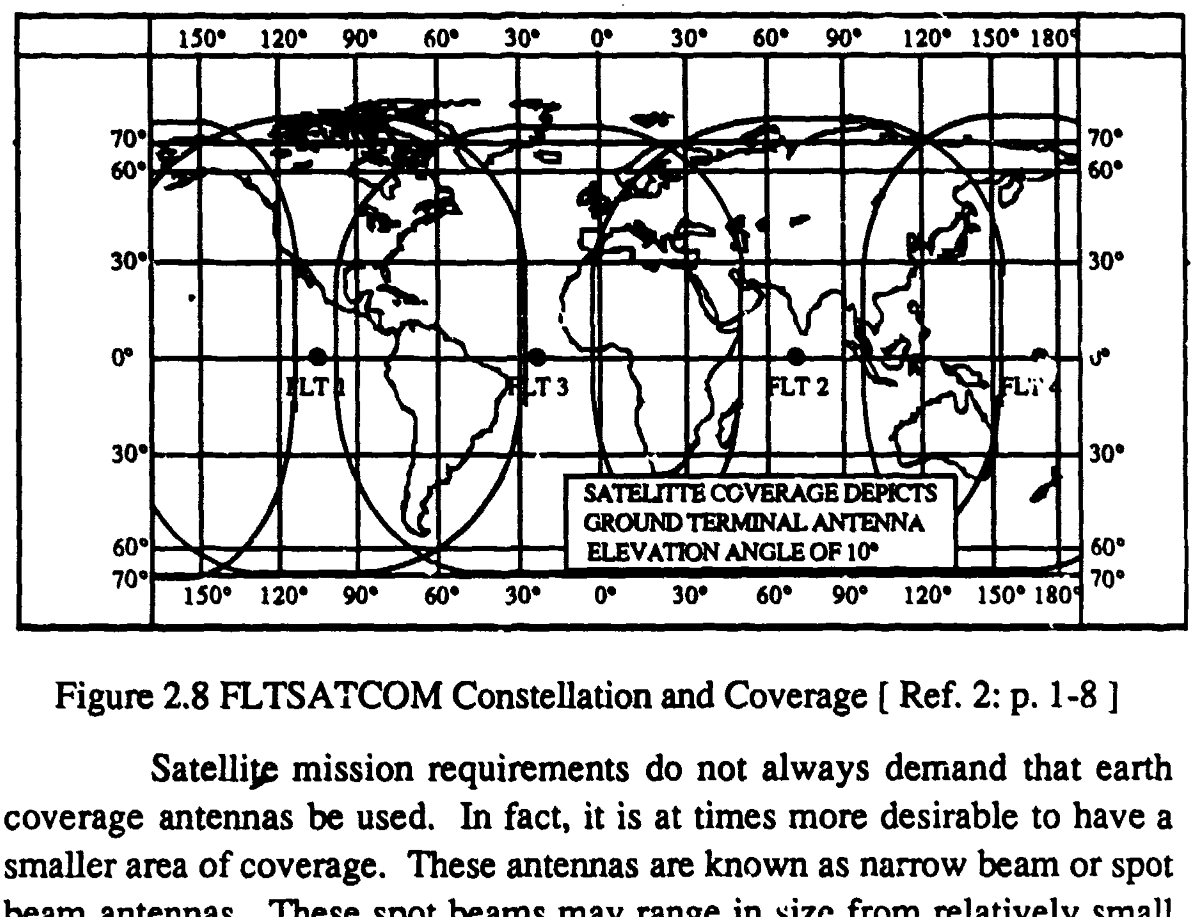


Figure 2.8 FLTSATCOM Constellation and Coverage [Ref. 2: p. 1-8]

Satellite mission requirements do not always demand that earth coverage antennas be used. In fact, it is at times more desirable to have a smaller area of coverage. These antennas are known as narrow beam or spot beam antennas. These spot beams may range in size from relatively small

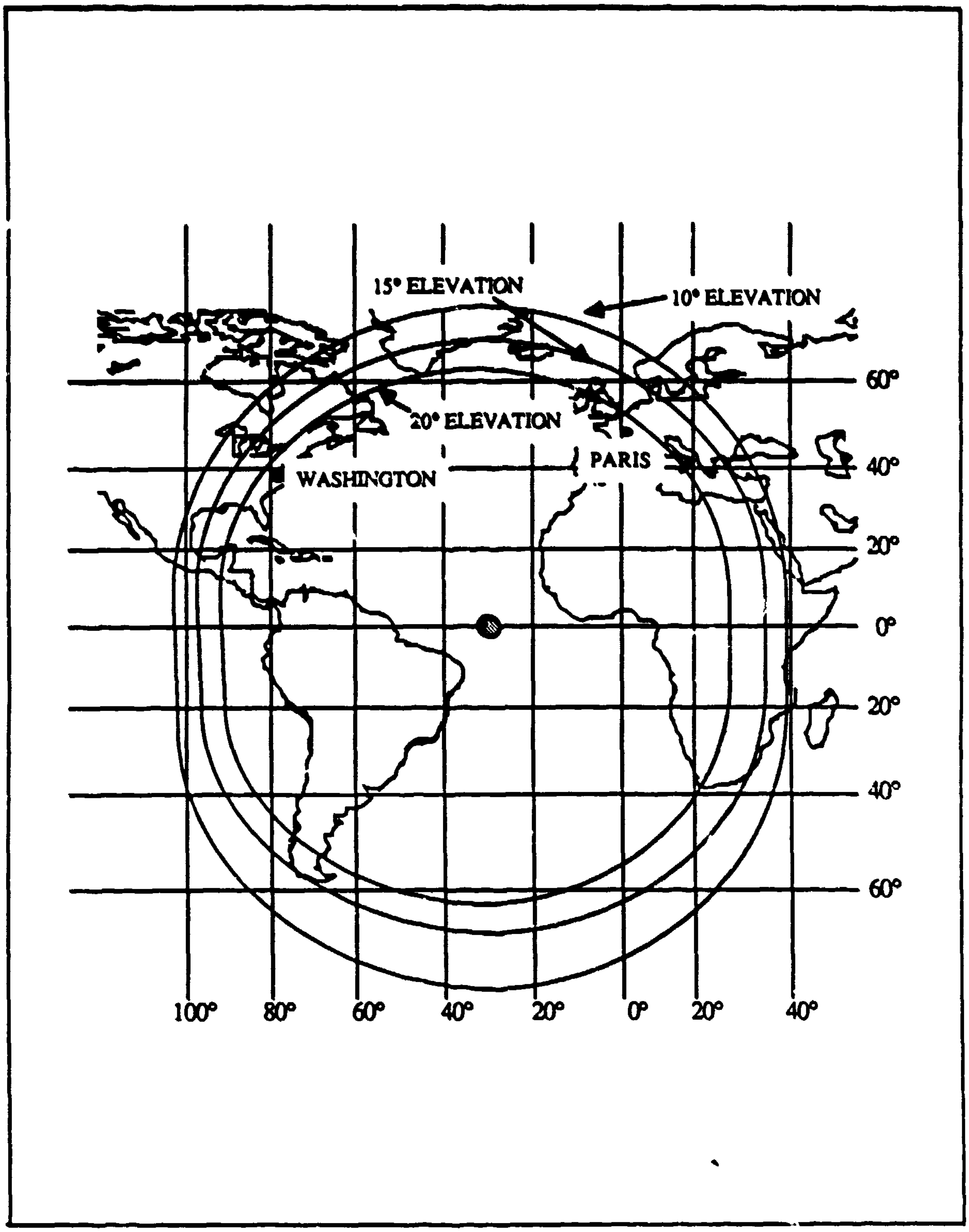


Figure 2.7 Coverage Contours for a Synchronous Satellite at 30° West Longitude [Ref. 2: p. 2-6]

beams that are used with a multiple beam or beam hopping antenna system to a large spot beam that covers just one country. Table 2.2 shows several examples of spot beam diameters for given antenna beamwidth at geostationary orbit. Figure 2.9 illustrates examples of the different types of beams. The narrower the beam the higher the gain within the footprint, or spotbeam coverage area. This decreases the size of the ground terminal antenna required because the required receive signal levels can be achieved across a smaller antenna area with the higher gain. Power from ground terminals to satellites is not usually a problem because the transmit power capabilities for most ground terminals are not faced with the same constraints (i.e. size, weight, radiation effects, etc.) as satellite systems.

TABLE 2.2 VARIOUS BEAMWIDTHS WITH CORRESPONDING COVERAGE AREAS [Ref. 3: p. 127]

BEAMWIDTH	EARTH COVERAGE DIAMETER (MILES)
10°	3921
5.7°	2235
2.8°	1117
1.0°	392
.57°	223

Before closing this section, a brief description of three key techniques in understanding satellite communications will be provided. They are frequency division multiple access (FDMA), time division multiple access (TDMA), and demand assigned multiple access (DAMA). All three of these techniques are important ways the satellite and the ground terminals talk to each other.

In FDMA each earth station is assigned a specific frequency on which to transmit and receive within the bandwidth of the satellite. Therefore, there may be multiple stations accessing the same satellite at the same time but because they are at different frequencies there is no interference. This is the simplest of the three accessing techniques and it is

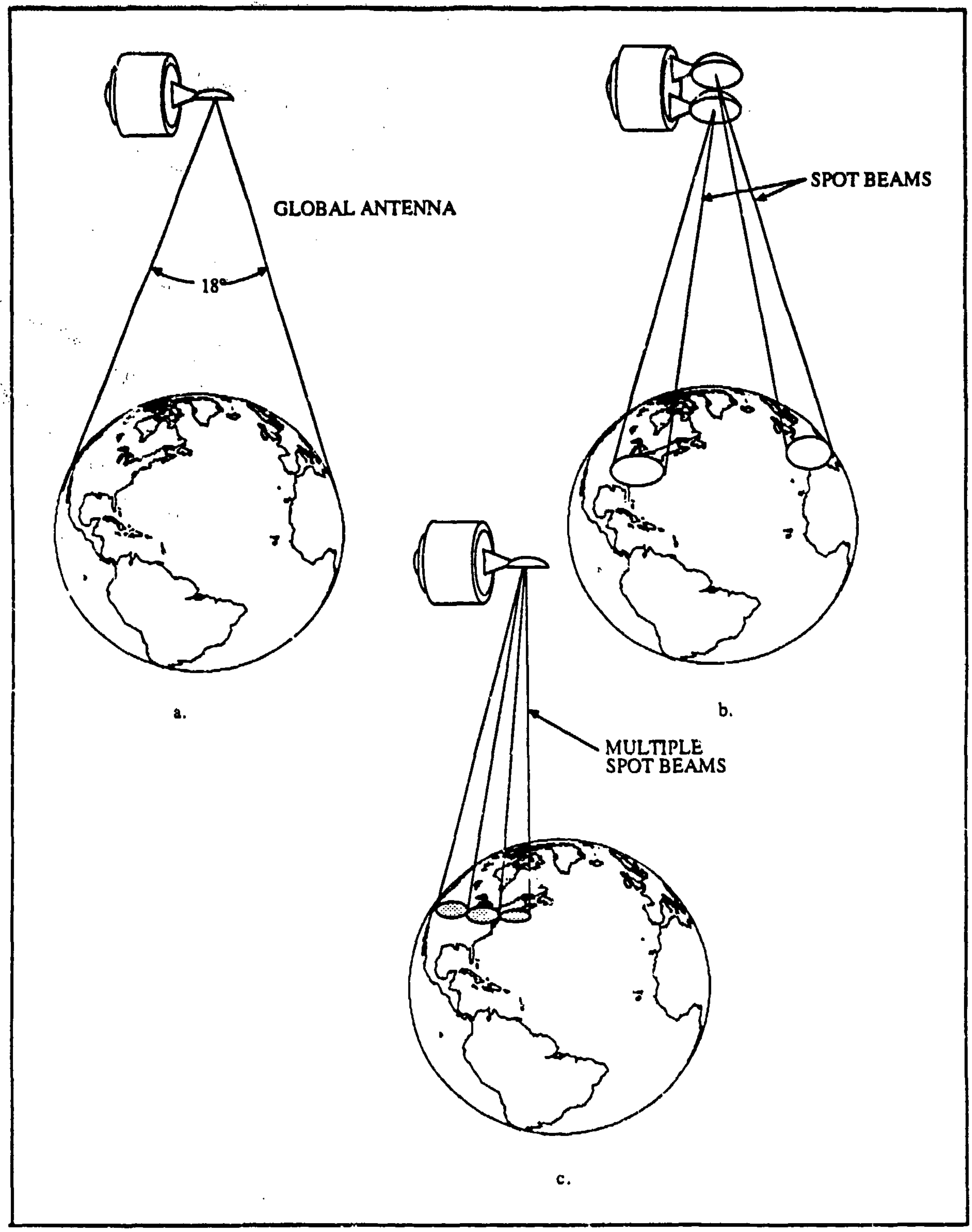


Figure 2.9 Antenna Beams [Ref. 3: p. 127]

used the most. In TDMA, instead of each earth station assigned a different frequency, the stations are assigned a different time slot. Therefore, all stations operate on the same frequency but only at different times. This type of technique requires much greater precision and control and requires short burst communications. DAMA is not a separate technique from FDMA or TDMA but is used in conjunction with those techniques. In DAMA the earth station requests only that portion of the frequency band or time slot necessary to transmit the desired traffic. This allows a more effective use of the transmission capacity because each station will only use what is necessary leaving the remainder for other additional users. This technique involves even more complex control and timing systems. This brief description of these three techniques will suffice for the discussions in later chapters. [Ref. 3: pp. 21-23, 193]

B. FROM ARTHUR C. CLARKE TO TODAY

> It will be observed that one orbit, with a radius of 42,000 km, has a period of exactly 24 hours. A body in such an orbit, if its plane coincided with that of the earth's equator, would revolve with the earth and would thus be stationary above the same spot on the planet. It would remain fixed in the sky and unlike all other heavenly bodies would neither rise nor set.
>
> Let us now suppose that such a station were built in this orbit. It could be provided with receiving and transmitting equipment (the problem of power will be discussed later) and could act as a repeater to relay transmissions between any two points on the hemisphere beneath, using any frequency which will penetrate the ionsphere. [Ref. 5: pp. 60-61]

Arthur C. Clarke's 1945 article, *Extraterrestrial Relays*, from which the above quote was taken, heralded the future 18 years before a satellite was placed in a geosynchronous orbit. Mr. Clarke, in fact, thought it doubtful that he would see the advent of communications satellites in his lifetime [Ref. 5: p. 64]. The expansion of the satellite communications field in the relatively few years since its introduction has been meteoric. However, the use of space to enhance communications did not immediately

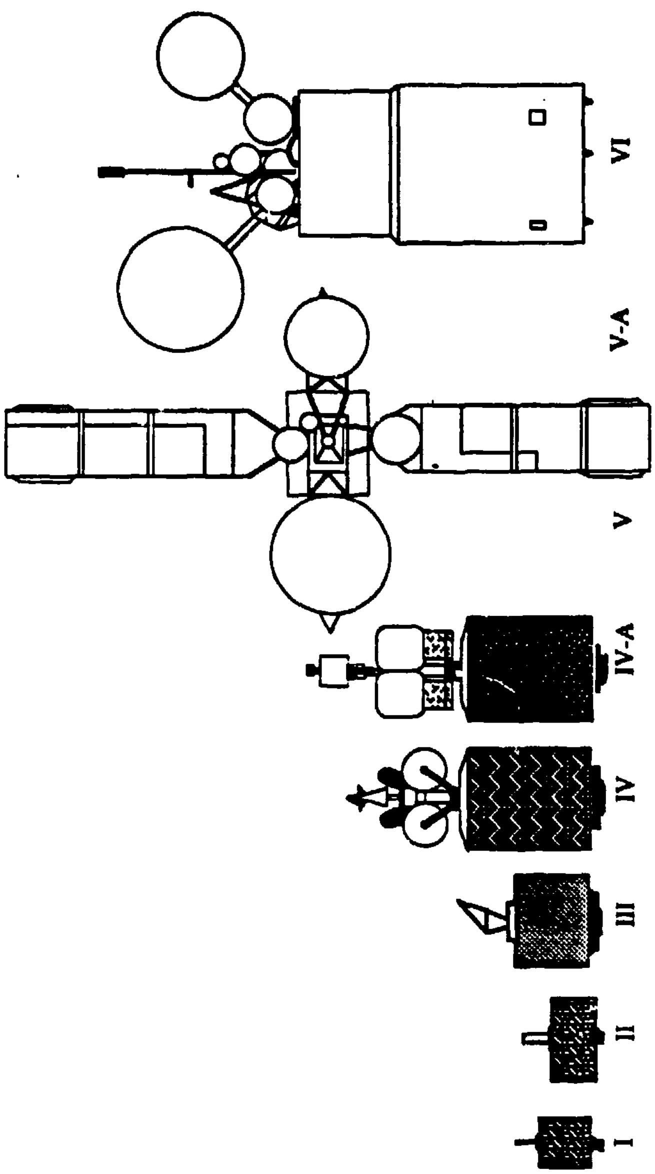
take off after Mr. Clarke's article. Efforts started modestly with the reflection of radio beams off passive objects such as the moon in 1954 and in August 1960 a large space balloon, code named Project Echo. The inherent reliability of these two relay systems could not offset the limitations imposed by the massive power and antenna requirements necessary for only a corresponding return of a few voice channels [Ref. 2: p. 1-2]. It was not until the late 1950's and early 1960's that experimental communications satellites were launched. Table 2.3 lists the early satellite programs that have furthered the development of commercial communications systems. Two points to note from the table are the increasing duration of the missions and the increasing communications capability. After SYNCOM III brought the Olympic Games to the United States from geostationary orbit in 1964, the commercial communications satellite evolved to become a major force in the world communications industry.

A major player in the communications field is the International Telecommunications Satellite (INTELSAT) Consortium formed in 1964 with eleven member nations. Today, INTELSAT has over 100 members. INTELSAT's function is to manage all aspects of international satellite communications, including the building of satellites and ground terminals [Ref. 2: p. 1-5]. Each member nation has a company that represents it in INTELSAT. The Communications Satellite Corporation (COMSAT) represents U.S. interests. As a representative example of the increasing capabilities of commercial communications satellites, Figure 2.10 depicts the INTELSAT satellites from INTELSAT I to the yet unlaunched INTELSAT VI and their major characteristics.

Currently communications satellites find wide and varied uses in all aspects of the communications industry. Figure 2.11, taken from a paper by R.R. Lovell and C.L. Cuccia of the Communications Division, NASA Headquarters,shows the major areas in which satellites find current opportunities and the projected trends for the future. It is assumed for the purposes of this discussion that the lines represent that capability's performance in the marketplace in terms of usage. Part of a study done by the American Satellite Company concluded that the total U.S. telecommunications revenue, which for 1984 was $47.6 billion, will rise to

TABLE 2.3 EARLY COMMUNICATIONS SATELLITE PROGRAMS
[Refs. 2: pp. 1-3, 1-4, 6: pp. 252-255]

SATELLITE	LAUNCH DATE	WEIGHT (LBS)	ORBIT	MISSION	MISSION DURATION
PROJECT SCORE	18 DEC 1958	150	ELLIPTICAL (Apogee 920 mi)	DELAYED AND REAL TIME TRANSMISSION OF VOICE AND TELETYPE	12 DAYS
PROJECT COURIER	4 OCT 1960	500	CIRCULAR (Radius ≈ 600 mi)	TESTING OF DELAYED AND REAL TIME VOICE, TELETYPE AND FACSIMILE	17 DAYS
PROJECT TELSTAR			ELLIPTICAL (Apogee 4030 mi)	PROVIDED TESTING FOR TELEPHONE, TELEVISION, FACSIMILE, AND DATA AMONG THE U.S., GREAT BRITAIN, FRANCE ITALY AND JAPAN	UNTIL MARCH 1965
TELSTAR I	10 JUN 1962	170			
TELSTAR II	7 MAY 1963	170			
PROJECT RELAY			ELLIPTICAL (Apogee 5307 mi)		
RELAY I	13 DEC 1962	172		SUPPORTED COMMUNICATION TESTS BETWEEN U.S., EUROPE, AND SOUTH AMERICA	UNTIL FEBRUARY 1965
RELAY II	21 JAN 1964	172		USED BY U.S. GROUND STATIONS FOR COMMUNICATION TESTS	UNTIL SEPTEMBER 1965
PROJECT SYNCOM					BOTH SATELLITES WERE TURNED OVER TO DOD BY NASA IN 1965 AFTER TESTING
SYNCOM I	FAILED				
SYNCOM II	26 JUL 1963	86	INCLINED GEOSYNCH	USED FOR COMMUNICATIONS TESTING	
SYNCOM III	19 AUG 1964	83	GEOSTATIONARY	USED TO TRANSMIT TOKYO OLYMPIC GAMES IN FALL OF 1964 DEMONSTRATED FEASIBILITY OF SATELLITE IN GEOSYNCH ORBIT	



INTELSAT DESIGNATION	I	II	III	IV	IV-A	V	V-A	VI
YEAR OF FIRST LAUNCH	1965	1966	1968	1971	1975	1980	1983	?
DIMENSIONS (Undeployed)								
WIDTH, m	0.7	1.4	1.4	2.4	2.4	2.0	2.0	3.6
HEIGHT, m	0.6	0.7	1.0	5.3	6.8	6.4	6.4	5.3
COMMUNICATIONS MASS PAYLOAD, Kg	13	36	56	185	190	235	280	600
DESIGN LIFE, YEARS	1.5	3	5	7	7	7	7	7
VOICE CHANNEL CAPACITY IN AOR	480	480	2400	8000	12000	25000	30000	80000
BANDWIDTH, MHz	50	130	300	500	800	2300	2180	3680

Figure 2.10 Evolution of INTELSAT Satellites [Ref. 7: p. 17]

$76 billion by 1989. Of that total, satellites were competitive for approximately one-half the 1984 amount with the same share predicted for the 1989 amount. It is apparent that from their humble beginnings communications satellites have evolved to form a major portion of the communications environment. [Ref. 9: p. 129]

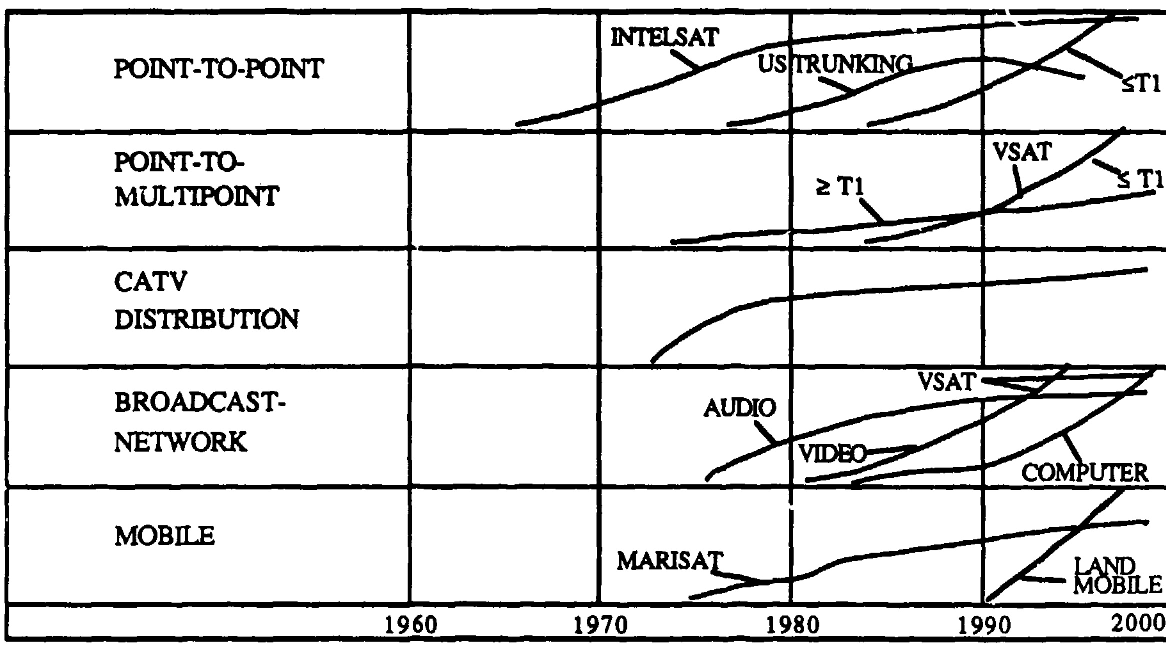


Figure 2.11 Communications Satellites Trends and Opportunities [Ref. 8: p. 1]

C. FIBER OPTICS--THE TECHNOLOGY

To better understand the role of satellites in future communications systems, it is important to be familiar with the technology that is most affecting that role.

The most significant development in terrestrial technology has been the fiber optic cable. Actually, the real technology breakthroughs were the development of the solid state laser which transmits the light through the fiber cables and the realization of very low loss single-mode fibers. By whatever name, laser-driven fiber optic cables are having a profound effect on our communications system and our concepts of the role of communication satellites. [Ref. 8: p. 2]

This section briefly examines the basic concepts of fiber optic systems allowing the reader to better understand the impact of fiber optics on the communications industry.

The basis of fiber optic technology is the transmission of light through a thin fiber strand, usually 0.125 mm or less in diameter, made from plastic compounds, silica-based materials, or a combination of both. This optical fiber, connecting two endpoints, is a light guide through which the light energy passes from a modulated light source to a light detector. Figure 2.12 shows a longitudinal cross section of a typical fiber. Essentially, the fiber is made up of two dielectric materials which use the characteristic speed of light within these two materials to propagate the light energy in a useful form. Each of the two materials has an index of refraction based upon the formula:

$$N = \frac{c}{v}$$

where

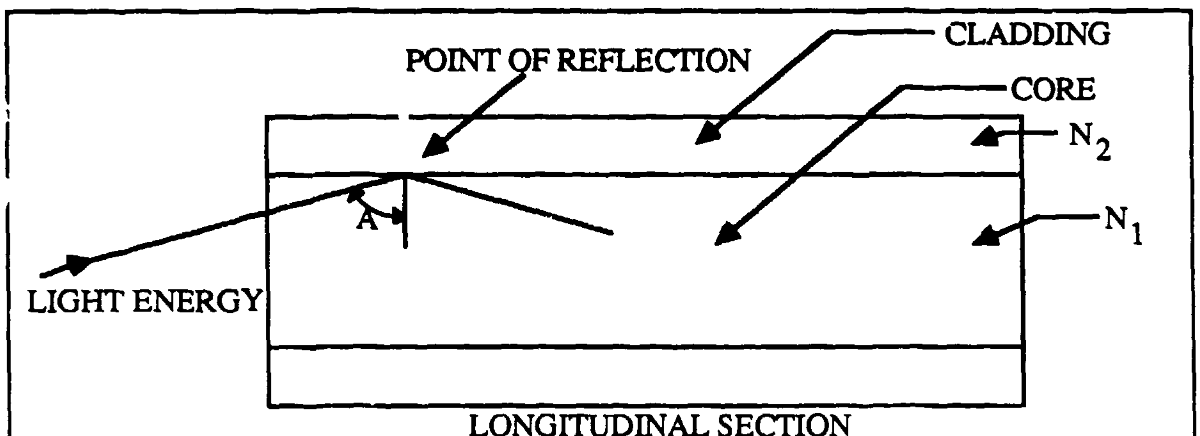
c=the velocity of light in a vacuum (3×10^8 m/s)

v=the velocity of light in the fiber.

This formula is part of Snell's Law, which states that the light energy incident on the boundary between the two dielectrics will be reflected if the angle of incidence is greater than A_{min} as depicted on Figure 2.12. Some typical values for the index of refraction, which is material dependent, are shown on Figure 2.12. Using these values and Snell's Law as an example (the calculations are shown at Figure 2.12) it is determined that those light energy waves that are incident to the boundary between the two dielectric materials by more than 80.57° will continue to propagate down the fiber core [Ref. 2: pp. 7-25, 7-27].

There are basically two types of fiber: monomode (single-mode) and multimode. Single-mode fiber is sufficiently small in diameter to allow for the transmission of a single light energy wave. This allows for low light attenuation and wide bandwidth capability. The bandwidth is related to the rise to fall time of the signal pulses. The shorter the rise to fall time the greater the bandwidth. Therefore, the single mode with less attenuation and distortion has shorter rise to fall times thus a greater bandwidth available than the multimode. Intermodal dispersion refers to the light rays moving

down the fiber on different paths at different velocities. The difference in velocities cause distortion in the signals at the terminating end. This causes longer rise to fall times of the pulses and decreases the available bandwidth. Multimode has a larger diameter thus allowing for many paths along the fiber. This increases intermodal dispersion and decreases the available bandwidth [Ref. 2: p. 7-27]. Good quality multimode fibers can transmit 1000 Megabits per second (Mbps) over 1 km. If the data rate is lowered to 100 Mbps, the spacing between repeaters can be increased to 10-20 km. Single-mode fiber can transmit up to 200 Mbps through 80-100 km of fiber without the need for regeneration. [Ref. 10: pp. 203-204]



$$\sin A_{min} = \frac{N_2}{N_1} = \frac{1.46}{1.48} = .98649 \longrightarrow A_{min} = \sin^{-1}(.98649) = 80.57°$$

Figure 2.12 Light Propagation in Optical Fiber [Ref. 2: p. 7-25]

The major components of a typical fiber optic system are shown at Figure 2.13. The diagram gives a basic explanation of how the system works. As depicted in the diagram, the fiber optic cable is merely the medium by which the light travels. The remaining important portions of the system are the transmitter, the receiver, the optical repeater and, although not shown, the connectors.

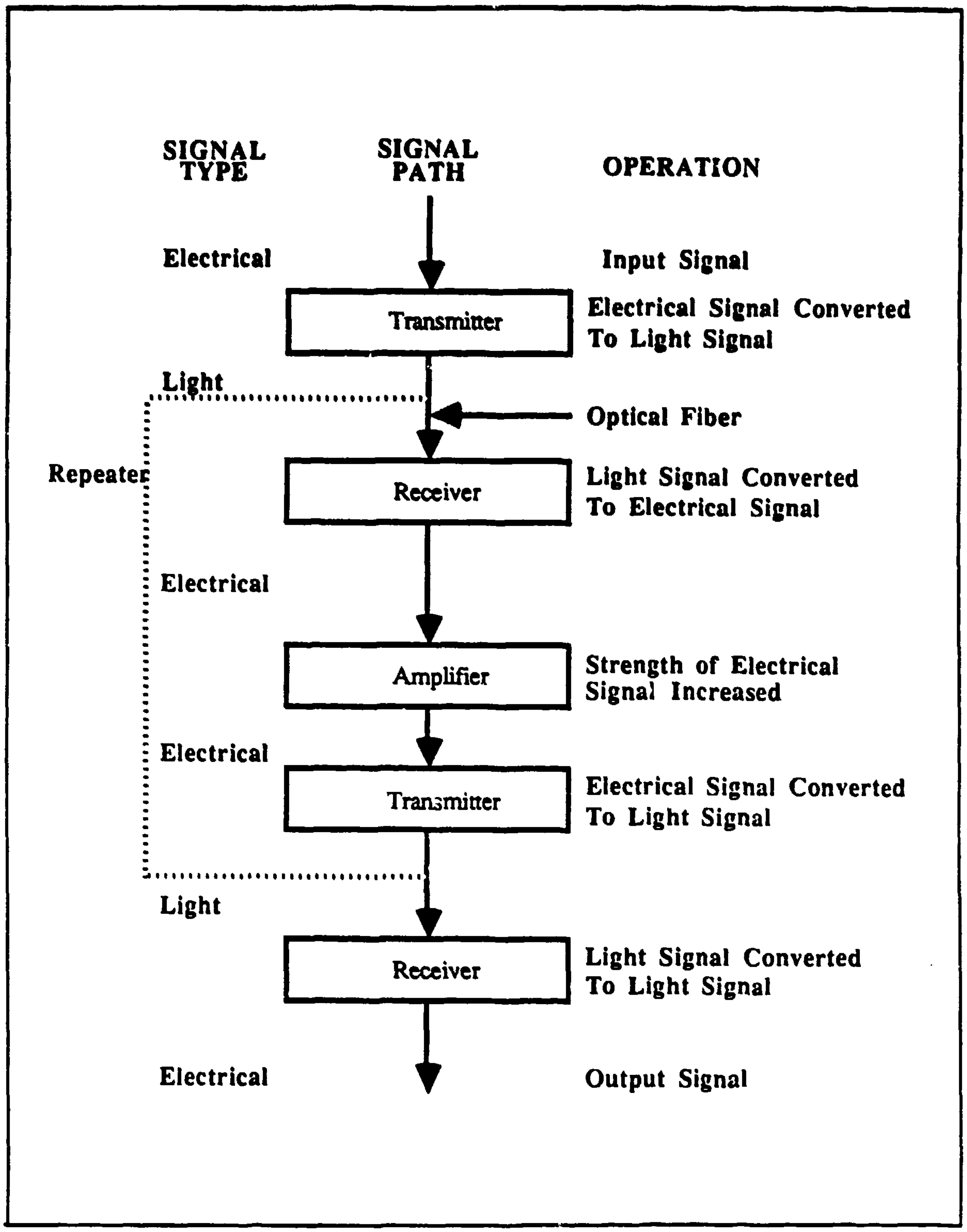


Figure 2.13 Basic Fiber Optics Communications System [Ref. 9: p. 339]

The transmitter is essentially a light source. It converts the incoming electrical signal to a light pulse using either a semiconductor laser diode or a light emitting diode (LED). The laser diode emits a more concentrated light pulse than the LED. The wider angle emission of the LED causes it to lose much of its power in coupling to the cable. Therefore, lasers are generally used for the longer distance systems while less expensive LEDs are used for shorter distances [Ref. 11: pp. 338-340]. Additionally, LEDs have a typical pulse rise/fall time of 3 to 5 nanoseconds (ns) which limits their use to bit rates of less than 50 Mbps. Pulsed lasers, have a typical rise/fall time of 200 pico seconds (ps) which allows them to be used in 1 Gbps and higher data rate systems. [Ref. 2: pp. 7-29, 7-30]

Optical repeaters perform essentially the same function as conventional wire system repeaters, that is detecting and regenerating an attenuated incoming signal. The attenuation is due to the dispersion and absorption of light over the length of cable. The repeater, as described in Figure 2.13, receives and converts the light signal to an electrical signal, amplifies it, and then reconverts it to light prior to transmission. [Ref. 11: p. 341].

Receivers in an optical system are semiconductor diodes that detect the incoming light and convert it to an electric signal. There are two types of detectors, regular photo diodes and avalanche photo diodes (APD). APDs are more sensitive than regular diodes due to internal amplification. The amplification causes a greater current flow for the same input power producing a gain in the signal strength. A small light signal coming in will produce a significant electrical pulse. [Ref. 11: p. 341]

Connectors are essential to the fiber optic system. They pass the light among fiber, transmitters, receivers or other optical equipment with a minimum of loss. Connectors are designed for the connection of single or small numbers of fibers. Loss values across the connectors may range from 0.1 to 2 dB depending on the connector and system requirements [Ref. 2: p. 7-30]. An example of a biconical design connector is shown in a schematic drawing at Figure 2.14. The losses for this connector are typically less than 1 dB [Ref. 12: p. 181].

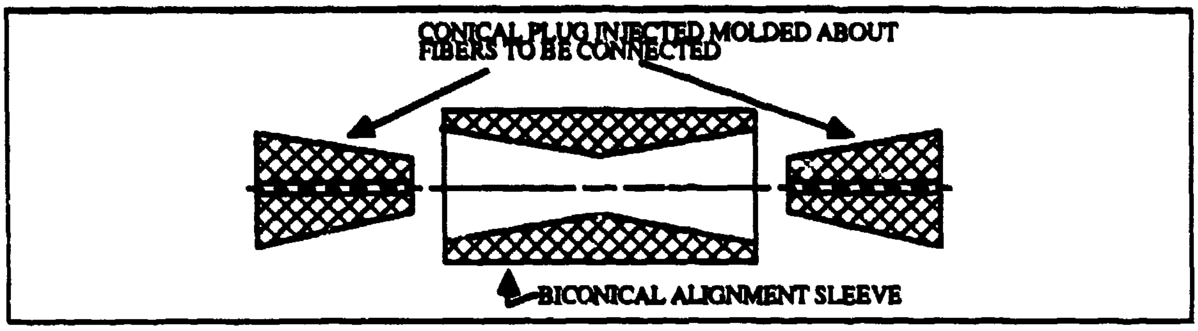


Figure 2.14 Schematic Illustration of Biconical Design Developed by Bell Laboratories [Ref. 12: p. 182]

D. THE FIBER OPTIC IMPACT ON SATELLITE COMMUNICATIONS

This section examines the impact of the emergence of fiber optic communications on the satellite communications industry. Two quotes from an article, *Trends in Fiber Optics*, by John F. Lynch in the June 1985 Signal magazine [Ref. 13: pp. 33-35] provide a view of the fiber optic future. He concludes that fiber optics

> provide a digital transmission capability that far exceeds copper wire and radio based media and that is capable of meeting the most demanding needs of the information age. Wideband real time video, high speed data and narrowband voice communications can be realized in a lighter weight media less than 10 microns in diameter at lower cost--once a concept, now a reality.

He further states that,

> for long haul systems, the impact of repeaterless transmission over thousands of kilometers is spectacular in that it enables us to span oceans or continents with low cost, highly reliable lightwave systems.

As an example, early fiber systems that connected cities, circa 1980, used the AT&T FT3 system with a data transmission rate of 45 Mbps.Currently, this system is being upgraded to an FTX-180 system which is capable of 180 Mbps. Emerging soon is AT&T's newest commercial system, the Series G, which is being upgraded to 1.7 Gigabits per second (Gbps) data rate [Ref. 14: p. 2]. Additionally, research has

shown the possibility of transmitting information along fibers at rates approaching 1x10^{12} bps. The capability for data rates of 20 Gbps over 68 km and for 50 Gbps rates achievable by multiplexing individual 2 Gbps systems has been demonstrated by Bell Labs. [Ref. 15: p. 2]

In addition to the capability for immense data rates, the low cost of fiber optic cable is a major factor in the expansion of fiber use. Because fiber cables are made from abundant silica or plastic, the cost has been relatively low and getting lower as the demand increases. The monomode fiber cable that is being sold for 20-40 cents per meter is expected to drop to a low of 4 cents per meter in the near future. The cost range is dependent on the attenuation quality of the fiber. [Ref. 15: p. 1]

The factors mentioned above, high data rates and low cost, as well as the small cable diameter, upgradability, long system life, high reliability, low bit error rates, and excellent security capabilities have worked together to cut a niche in the communications industry for fiber optics that is steadily growing. An apparent consensus among attendees at the 1986 International Conference on Satellite and Fibre Optic Communications yielded rural areas and mobile users to satellites while agreeing that fiber optics would force satellites out of point-to-point communications between populated areas [Ref. 16: p. 117]. Aviation Week and Space Technology (AW&ST) magazine has quoted Henry M. James, director of network design for Satellite Business Systems' (SBS) national network, as stating "it could be economical to transmit coast to coast on fiber" [Ref. 9: p. 127]. Currently, the break point, that area where it becomes more cost efficient to use satellites rather than terrestrial systems, ranges between 500-1000 miles. From the same AW&ST article above, SBS considers this break point to be approximately 1000 miles, while figures taken from NASA information show an approximate 700 mile figure. Another article in Commercial Space magazine mentions a 500 mile break point [Ref. 17: p. 64]. Although the figures vary the point is that once the break point was passed then the *bent pipe* satellites traditionally filled the role for communications. This is where fiber optic systems have had the most significant impact.

Returning to Figure 2.11, a key point to highlight is the trend in the point-to-point role for U.S. trunking. As reflected in the diagram, U.S.

trunking is beginning to level off with a projected decrease becoming apparent in the early 1990's. The trend reflects the emergence of fiber optic systems and the retreat of satellite systems from point-to-point U.S. trunking [Ref. 8: p. 1]. The projected 1995 AT&T Lightwave Transmission Network, shown at Figure 2.15, is a more visual indication of the encroachment of fiber optics into the satellite domain.

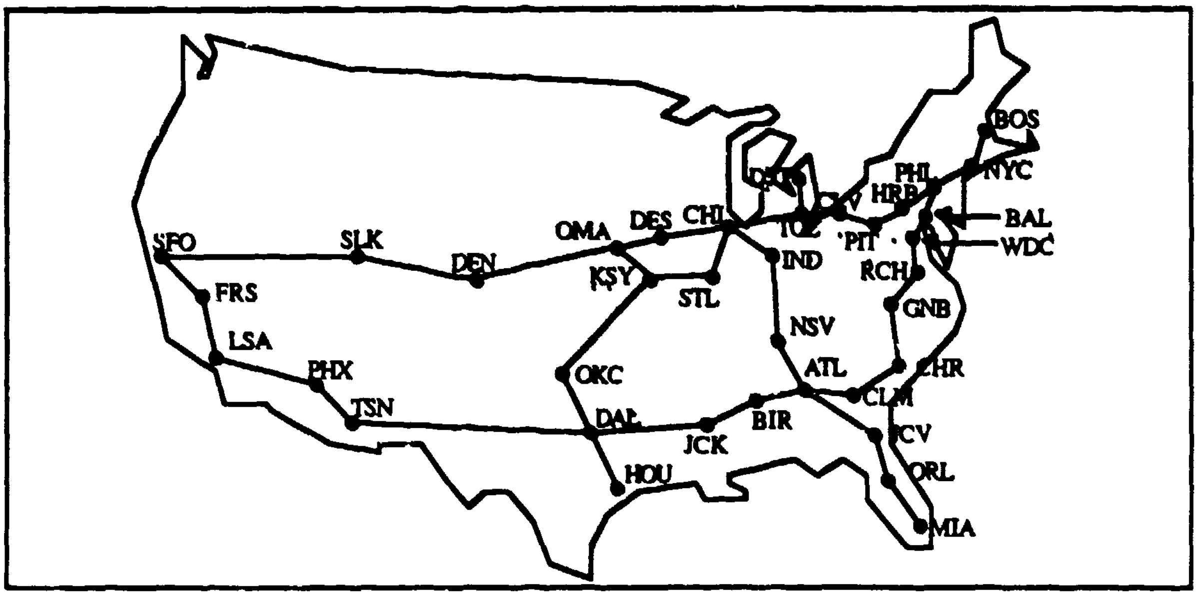


Figure 2.15 Potential AT&T Lightwave Transmission Network--1995 [Ref. 11: p. 375]

The battle for the communications business at the transcontinental level may be more difficult to determine. From Figure 2.11, the trend for INTELSAT point-to-point appears to be climbing toward the end of the century, however, that change may in fact be more of a leveling off. A conference paper, *Satellites Versus Fiber Optic Cables: The North Atlantic Case* [Ref. 18: pp. 39-40], reports the expected decline of traffic carried on satellites from 50 to 35 percent by 1993 with an even larger drop expected in later years. This could equate to a revenue loss of 500 million dollars over ten years. The factor influencing this decline is the installation of a transcontinental fiber optic cable (TAT-8) due to be operational in 1988. However, the report then shows that INTELSAT VI, the next generation of satellite, can compete with the TAT-8 cable in both capacity and cost.

However, Table 2.4 and the following quote, both from a conference paper by Dr. H.S. Braham, Manager of Advanced Communications Satellites at TRW [Ref. 19: p. 1], conclude that the cost of fiber optic systems is still expected to be cheaper than satellites even at the transcontinental distance of 3000 miles.

> Fiber will greatly curtail the missions of current satellites in two-way service. Point-to-point trunking, e.g., GTE SPRINT and SBS SKYLINE, produces most of today's satellite revenues for two-way service. However, this satellite use will soon be [obsoleted], since fiber will reduce the current terrestrial cost of transmission by a factor of 10 or more and be much cheaper than satellite transmission even on transcontinental links.

The point of this section is to show the impact of fiber optic systems on satellite communications. The extent of the impact may vary with the

TABLE 2.4 TRUNKING [Ref. 19: p. 1]

TRANSMISSION COST (¢ per voice circuit minute)	DIGITAL MICROWAVE	SATELLITE	FIBER*
700 mile (average distance)	1	1	1/20
3000 miles	4	1	1/5

* Assumes full loading

Fiber destroys satellite transmission niche, which is distance of 700 to 3000 miles.

viewpoint but the the fact that a major force has emerged is not questioned. The traditional use of satellites in the point-to-point movement of information is suffering under the emergence of fiber optics. The case for fiber optics taking over point-to-point trunking within most of the U.S. is expected, eventually. The intercontinental market may be a more debatable issue but the fact that the use of fiber systems will cause a negative impact on satellite systems is not in question. As that portion of the market starts to slip away from the satellite industry, a concerted effort is required to develop and

expand those areas in which satellites can be cost effective. Referring to Figure 2.11, it is apparent that there are several other areas in which a satellite's special capabilities may be used. The trends indicate that expected growth is likely in all areas except point-to-point trunking. While the *bent pipe* satellite is becoming obsolete versus fiber optic systems, a new dynamic satellite capability may open new markets for the communications satellite. Figure 2.11 projects a rapidly increasing trend for satellite point-to-point circuits with a capacity of up to a T-1 (designation for a circuit that has a 1.5 Mbps data rate capability) data rate. The capability of emerging satellite technology to take advantage of this opportunity is what the ACTS program is based on in order for satellites to regain some ground in a diminishing market with the emergence of fiber optic systems. It is hoped that the ACTS program, discussed in the next chapter, with its state-of-the-art communications technology will be competitive with the fiber optic systems.

III. COMMERCIAL SATELLITE COMMUNICATIONS--TOMORROW

A. SATELLITES RESPONDING TO CHANGE

The information discussed in Chapter II clearly shows that commercial satellites are feeling the impact of fiber optics' emergence into the marketplace. The trends in satellite opportunities shown in Figure 2.11 projects that point-to-point trunking, especially in the U.S., will be a failing market for satellites in the next decade. Other areas listed in Figure 2.11 are in many ways uniquely suited to satellites; hence, the expected trends in those areas (mobile communications, video and computer broadcast, VSAT, etc.) are projected to continue rising. However, the communications satellite industry has not given up on the point-to-point market and is confident that new advances in communications satellite technology will re-establish satellites as a force in the market.

A feature of any terrestrial network, be it optical fiber, cable, or radio systems, is that its cost is based on a summation of the parts. This means the cost of using a circuit from end to end must take into account the costs of all the cables, switches, and repeaters between the two locations. The bulk of these costs are encountered following the long distance transmission path as the circuit moves down the different levels to the subscriber, commonly known as the *final mile.* The *final mile* also includes those costs incurred at the beginning of a circuit. These *final mile* costs may contribute as much as one-third of the total communications costs. If the costs for local exchanges and billing, engineering, and fixed plant are combined with the *final mile* costs, a figure as large as 60% of the total communications cost may result. This figure is independent of the distances involved. A NASA diagram, Figure 3.1, shows a pictorial representation of the current architecture for terrestrial switching, which highlights the idea of the *final mile*. [Ref. 14: p. 2]

Table 3.1 shows some typical costs for long haul business users. The information was presented by Dr. H.S. Braham of TRW at Worldcom '85 in

TABLE 3.1 APPROXIMATE LONG HAUL COSTS FOR BUSINESS USER [Ref. 21: p. 3]

Cost Item	Current AT&T (700 Mile Average Distance)	
	Switched Access (Small User) (Cents Per Voice Circuit Minute)	Special Access (Larger User)
Transmission (no fiber)	1	1
Switching	0.5	0.5
Access Charges (two ends)	16.0	• 4 (metropolitan)* • >>4 (remote)* • Increasing with time*
Billing	3.0	3.0
People		
Bell Labs	1.5	1.5
Other	3.0	3.0
Other operations including advertising	4.0	4.0
Profit	3.0	3.0
Total	**32.0**	**20.0+**

26¢ average Fortune 500 cost (mix of on and off-net)**

*AT&T's Alan Kuritsky (July, 1985) says Bell Operating Companies (BOC) requesting 40% tariff increase

**Values from TeleStrategies 1985 conference by AT&T and Monsanto speakers

October 1985. From the table, it is proposed that a major portion of the costs are attributable to categories other than transmission of the signal. Dr. Braham stated, in a telephone conversation on 20 May 1987, that he considers those costs associated with the *final mile* to be equated to the term access charges in Table 3.1, although he prefers the usage of the term access charges as more definitive. The term *final mile*, as described in the previous paragraph, will continued to be used in the following discussions.Thus, it would seem that significant cost reductions could be made if those costs associated with the *final mile* were eliminated or reduced regardless of the transmission path.

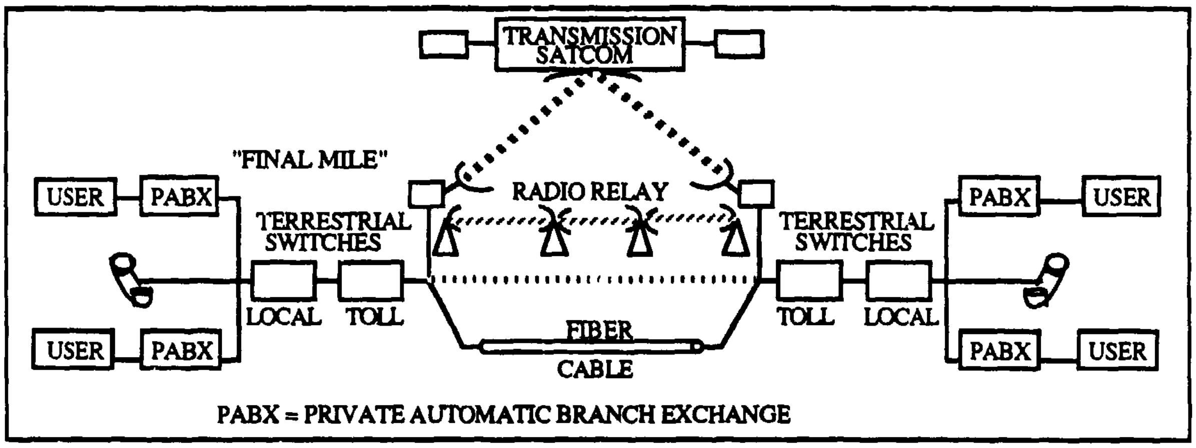


Figure 3.1 Current Architecture Terrestrial Switching [Ref. 20]

The terrestrial communications systems have inherent problems with their ability to reduce or eliminate these *final mile* costs. A case in point is fiber optic communications. Fiber optic systems are most effective economically when fully loaded at high data rates. However, the competitive edge for fiber optics starts to deteriorate as the data rate moves lower and is not competitive at 1.544 Mbps and below. Figure 3.2 illustrates the problem of reaching the user and keeping the fiber optic system cost effective. The cost of going from the very high capacity trunks to the local user represents the high cost of the *final mile* for fiber optics. While all systems have some sort of hierarchy to traverse to get to the user, the capability of the satellite system to terminate at the user significantly reduces the levels of hierarchy. Terrestrial systems, on the other hand, normally has a more extensive

hierarchy to traverse thus it is conceivable that a higher cost may be the result. [Ref. 8: p. 2]

As previously discussed, satellites are being pushed to expand and develop new areas of commercial use as the use of fiber optics expands. In the drive for cost effectiveness, satellites, by their unique advantages and technology advancements, could offer an answer to reducing the *final mile* costs. The solution, as depicted in Figure 3.3, is to bypass much of the switched network to get closer to the user.

Today, many corporations use a form of this bypass system by using very small aperture terminals (VSAT), located at the customer premises, passing information to a central node or hub via satellite. This provides these corporations with a cost effective method of collecting large amounts of random data from large numbers (possibly thousands) of locations. These networks, because they bypass the terrestrial system and are cost effective, are growing rapidly [Ref. 14: p. 4]. Figure 3.4 highlights the key

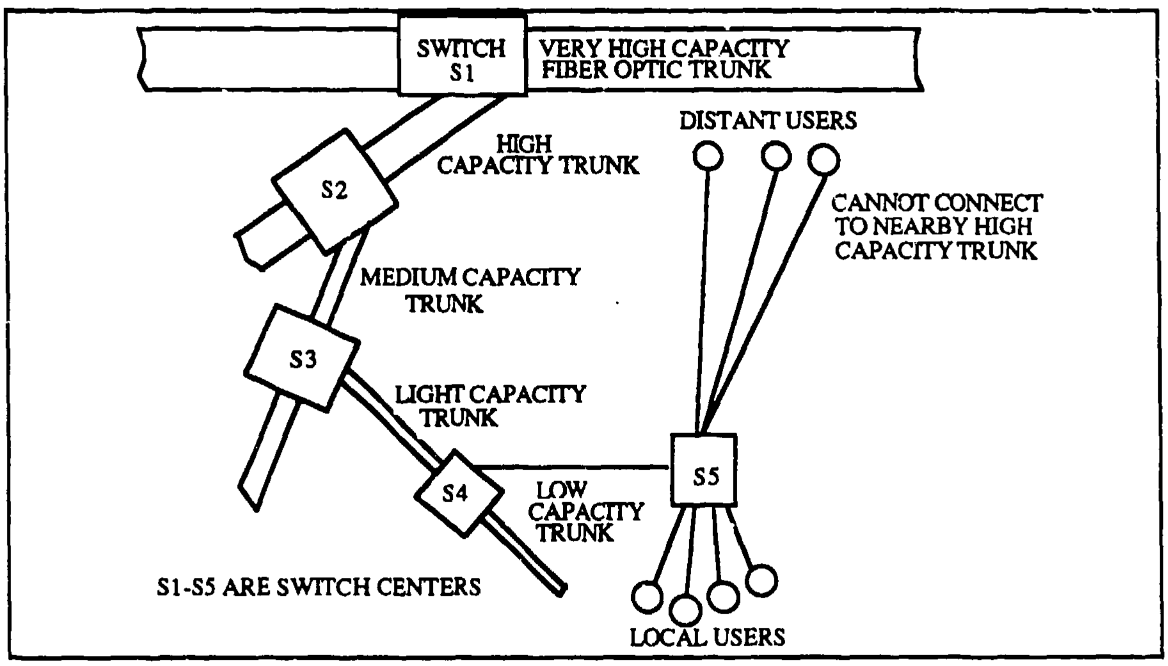


Figure 3.2 Access to the Fiber Network [Ref. 8: p. 4]

factors of the VSAT service. Additionally, Table 3.2, presented by Dr. Braham at Worldcom '85, is a list of corporations that were using or

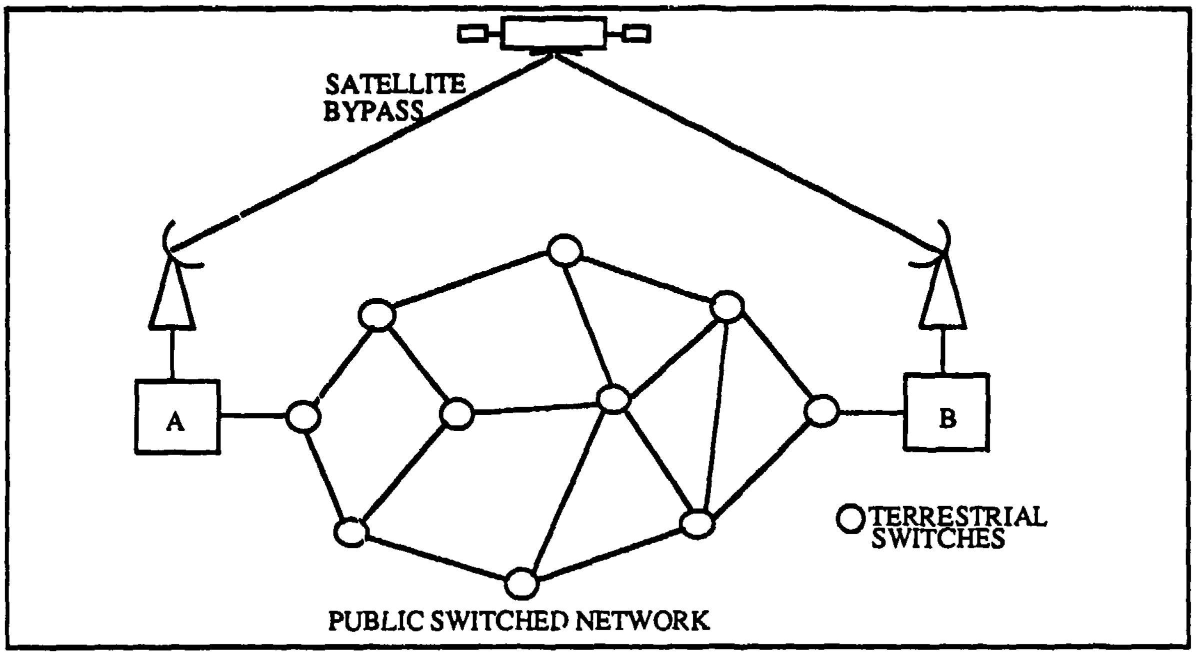


Figure 3.3 Satellite Bypass of Public Switched Network [Ref. 8: p. 3]

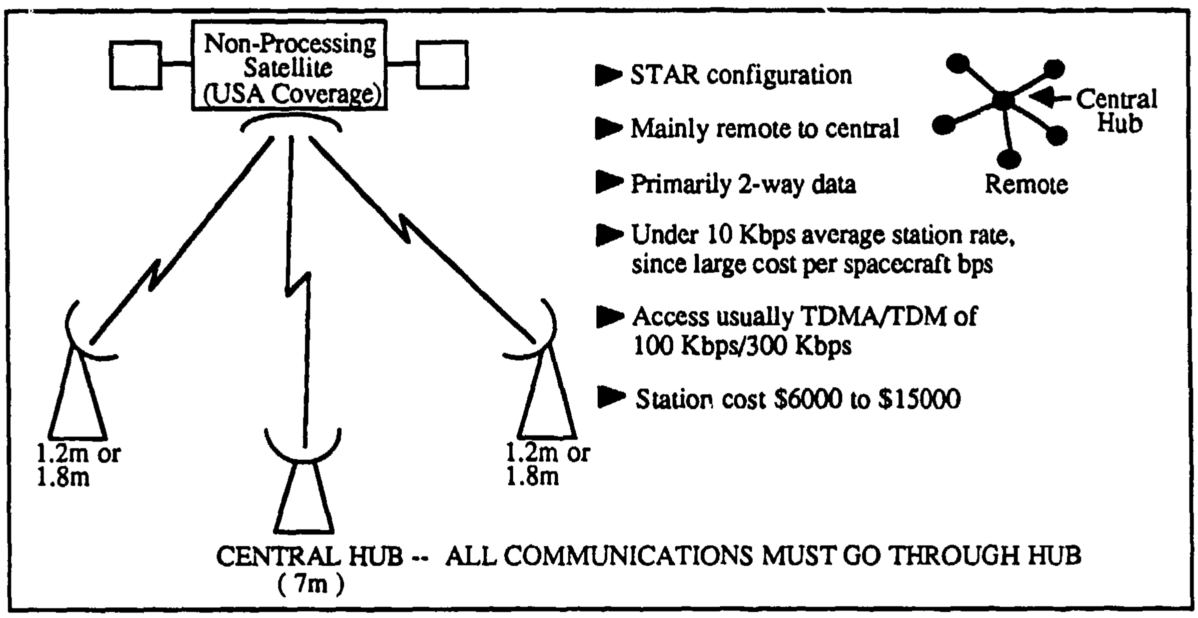


Figure 3.4 Very Small Aperture Terminal (VSAT) Customer Premise Service (CPS) [Ref. 19: p. 2]

planning to use a VSAT system. However, the VSAT system is not effective in terms of voice traffic which still comprises approximately 85% of all traffic. This limitation on voice traffic is a function of the delay due to the double hop communications. Double hop communications stems from the fact that all communications must pass through the central node, depicted in Figure 3.5. Another limitation is attributed to the amount of cost effective throughput possible. A non-processing satellite, i.e., bent pipe, cannot support the high data rate requirements desired by businesses on small terminals and be cost effective. [Ref. 19: pp. 3-4]

TABLE 3.2 VSAT CPS CIRCA 1985 [Ref. 21: p. 6]

	CUSTOMER	STATIONS	CONTRACTOR
	Schlumberger	>300	M/A COM
	Walmart	>800	M/A COM
	Southland(7/11)	>300	M/A COM
	Haliburton	Many	ASC/COMSAT Technology
	K-Mart	2300	GTE SPACENET
	Xerox	Many	Telecom General
	Mutual Broadcasting	About 1500	Unknown
Planned	GM/EDS	25,000	TBD
Planned	Federal Express	50,000 Zapmail	TBD
Planned	Many others (oil companies,IBM)	TBD	TBD
►	Customer puts up capital or long-term lease (3 to 10 years)		

The satellite communications industry believes that to take full advantage of the satellite's capabilities, a dynamic system incorporating the features of terrestrial switching but bypassing a significant portion of the *final mile* hierarchy is the next logical and competitive step for satellite communications. In accordance with these beliefs, several countries have initiated programs to develop those satellite capabilities required to make them competitive with terrestrial technologies in the next decade. The three

key technologies that are being developed are: (1) electronically hopped or scanning spot beam antenna systems, (2) satellite-based electronic circuit switches and (3) intersatellite communication links, primarily laser based with data rates in the several Gbps range. The U.S., Japan, and the European Space Agency currently have programs that are developing satellites incorporating these technologies. The U.S. program, known as ACTS, is a NASA-industry joint venture, will be described in the next section as the answer to providing a competitive edge to communication satellites. [Ref. 14: p. 5]

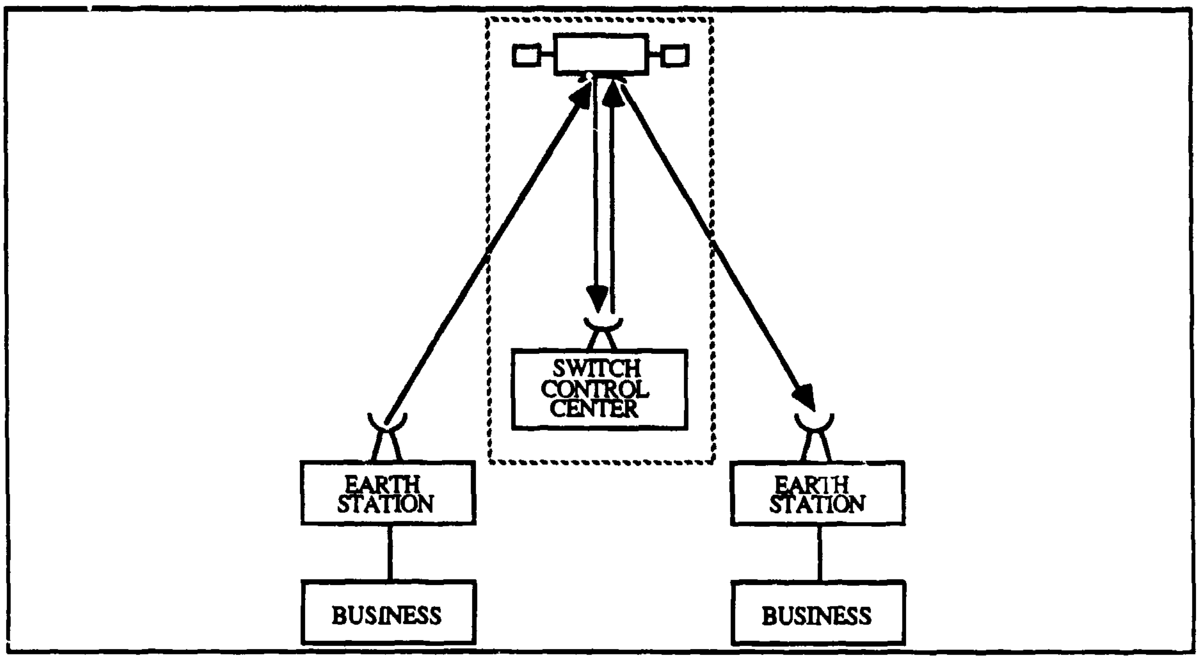


Figure 3.3 Ground Switched Satcom System [Ref. 8: p. 3]

B. THE ACTS PROGRAM

The NASA-sponsored ACTS program was developed to meet the requirement for a next generation of communication satellites. The ACTS program forerunners, Project SYNCOM, RELAY and the Applications Technology Satellite (ATS), also NASA sponsored programs, are credited with allowing the U.S. to dominate in the satellite marketplace. With the changing marketplace and communications environment, the need for a step

into the next generation of satellites is at its most critical point. [Ref. 22: p. 3]

A primary reason for the involvement of NASA in the SYNCOM, RELAY and ATS programs was that those programs represented the leading edge of the emerging field of satellite communications. As a result, these high technology programs were a high risk, high cost venture. The involvement of NASA provided government funding of these programs so that the risk assumed by industry was within their means. The result was the current dominance of U.S. satellite manufacturers. [Ref. 22: p. 5]

From NASA's and industry's point of view, the same situation now presents itself for the next step in satellite development. Although the satellite industry is well established, the development of a program to make that quantum leap is a significant demand on industry resources. NASA stipulates that the three main reasons that limit industry expenditures and necessitate government funding are the large investment necessary, a long time until payoff, and the high risk factor associated with the program. The expected annual expenditures for the ACTS program over the next few years is \$100 million. However, a reasonable range for a major satellite manufacturer to spend in advanced satellite development is only \$10-20 million. Due to the experimental nature of the ACTS program, a return on the investment may not be seen for as long as 10 years. This long delay in a return on investment severely limits the U.S. manufacturer's ability to participate. Finally, the last element is the high risk associated with the program. The technology involved in the program is on the leading edge; therefore, delays, deficiencies in performance, or system on-orbit problems may cause unacceptable risks in terms of the company's future. The combination of these three factors necessitated the need for government sponsorship to offset the drawbacks of the program and encourage industry involvement. The government sponsored agencies of Japan and the ESA are developing programs along the same lines as ACTS. [Ref. 22: p. 5]

The ACTS program is a *proof of concept* application of state-of-the-art technology for communications satellites. The purpose of the program is to put ground-tested new technologies in the environment of an actual flight system. The ACTS satellite will be launched from the Space

Shuttle in the 1989-90 time frame. The scheduled duration of the experimental program is two years. The ACTS program satellite will be a scaled down version of future satellites that will use the same technology.

The following extract from NASA'S ACTS: Notice of Intent for Experiments [Ref. 23] outlines the experimental program:

> The National Aeronautics and Space Administration (NASA) is conducting an Advanced Communications Technology Satellite (ACTS) Program to advance the high risk technology required to ensure continued United States' preeminence in the field of satellite communications. The objectives of the ACTS Program are to develop and validate the technology required to enable growth in the capacity and effective utilization of the frequency spectrum and to effect new and innovative uses for satellite communications.
>
> A primary goal of the ACTS Program is to make available to the public and private sectors (corporations, universities and government agencies) the capabilities of the ACTS spacecraft for experimentation. At this time, it is the intent of NASA to consider all experiments technically and scientifically relevant to the basic objectives of the ACTS Program and for which the ACTS System can accommodate. NASA will develop the flight system and provide access to the ACTS space segment at no cost to the experimenter. Each experimenter will be responsible for the conduct and funding of their experiment. [Ref. 23: p. 1]

In the following paragraphs, the ACTS will be described in a basic functional manner. No attempt will be made to provide an engineering level degree of detail, rather a simple description of the satellite and how it operates will be provided.

The ACTS program involves the testing and evaluation of many highly complex technologies. The complex nature of these technologies is beyond the scope of this effort. For the interested reader a list of the proof of concept technologies is shown in the Appendix. For this effort the basic description of the satellite and four critical technologies will be addressed to provide a basis for further discussions. The four technologies that will be discussed in relation to ACTS are the electronically hopped spot beams, the onboard baseband processor, customer premises satellite (CPS) terminals,

and laser intersatellite communications links. Several general aspects of the ACTS system will be briefl discussed before examining the four specific areas.

The satellite will be launched from the shuttle in low earth orbit (LEO) and moved to its permanent geosynchronous orbit at 100° West Longitude with the apogee kick motor (AKM). The satellite uses solar power and is three-axis stabilized. Three-axis stabilization means that the proper orientation of the spacecraft in space is maintained by various combinations of momentum wheels, reaction wheels, and thrusters [Ref. 7: p. 130]. Satellite tracking, telemetry, and control functions will be performed by the Master Ground Station (MGS) located near Cleveland, Ohio at the NASA Lewis Research Center. The control station also controls the ACTS communication system. Ground terminals communicate with the MGS via a separate communications engineering circuit commonly known as an orderwire. The terminals request or release 64 Kbps channels based on their requirements. As these requests come in, the MGS changes the programming in the baseband processor to accommodate the requirements. Synchronization and dynamic processing are critical elements of the ACTS system. The MGS communicates with both the satellite and the experimenter terminals to control system synchronization and demand access requirements. Additional information on the ACTS is provided in Table 3.3. [Ref. 24: pp. 197, 200]

TABLE 3.3 ACTS GENERAL INFORMATION
[Refs. 25: p. 4, 26: p. 8]

WEIGHT: 2843 LB. ON ORBIT
POWER: REQUIREMENT: 1770 WATTS
SOURCE: 4 SOLAR ARRAY PANELS (140 SQ FT TOTAL AREA)
DESIGN LIFE: 2 YEARS (POSSIBLE 4 YEAR MISSION LIFE)
FREQUENCY RANGE: UPLINK: 27.5-30 GHz
DOWNLINK: 17.7-20.2 GHz
CONTRACTORS: RCA, COMSAT, MOTOROLA, TRW

The ACTS communications system has two basic operational modes: high burst rate (HBR) and low burst rate (LBR). The HBR mode works with three fixed-spot beams at a data rate of 220 Mbps per beam. The purpose of

the HBR mode is to provide major trunking services for large communications users. Dr. H.S. Braham, in an interview on January 14, 1987 [Ref. 27], indicated that he did not believe that the HBR mode would be justified for the operational ACTS because it could not compete with fiber optic systems. Dr. Braham had previously stated this viewpoint in his paper, *Improved Satellite Cost and Performance Using ACTS Multi-beam Processing Satellites* presented at the AIAA Communication Satellite System Conference, San Diego, CA on March 18, 1986 [Ref. 19]. The validity of this position may be justified by further analysis but that is not within the scope of this effort. Therefore, further study of the HBR mode will not be made within the context of this thesis. Instead the thesis will concentrate on aspects of the LBR mode. The LBR mode incorporates the use of independent scanning, or electronically hopped, spot beams with the onboard baseband processor and small earth stations. The primary purpose of the LBR mode is to provide business users access to a dynamic, flexible system via small, cost effective earth stations. The ability of the system to fulfill this purpose is part of the experimental program. The individual satellite channels in the LBR system have a 64 Kbps data rate. The system operates at a maximum rate of 110 Mbps per beam of which any integer multiple of the 64 Kbps channels can be transmitted in a single burst. In this case, there are 1728 channels available within the 110 Mbps data rate. The laser intersatellite link, although not directly a part of the LBR system, will be discussed for its role as a link to other satellites in a network. The following paragraphs discuss the four highlighted technologies. [Ref. 28: pp. 188-192]

A critical portion of the LBR system is the scanning spot beams. The ACTS experimental system, as shown in Figure 3.6, has two pairs of these scanning beams, each beam pair assigned a specific section of the U.S. A simplified discussion of how the scanning beam works is given in the next paragraph.

As stated in Chapter II, a general rule of thumb for antenna beams is that the narrower the beam the higher the effective gain of the antenna system. The ACTS scanning beams have beam widths of 0.4°. This is smaller than the examples shown in Table 2.2, and corresponds to an approximate coverage

area diameter of 175 miles. The greater gain created by the narrower beam means that a terminal station within the footprint of the antenna can use a smaller antenna surface to operate within the system. By using the antenna hardware on the satellite, different antenna beams are turned on and off in a predefined order, thereby illuminating different areas on the earth with each beam. This series of footprints establishes a coverage area for the appropriate scanning beam and represents the apparent hopping of the beam. For the ACTS, each scanning beam covers an area approximately equal to 10% of the area of the U.S. Therefore, with the two beams on the ACTS experimental satellite, the coverage area is approximately 20%, as outlined on Figure 3.6. [Refs. 19: p. 1; 24: pp. 199-200]

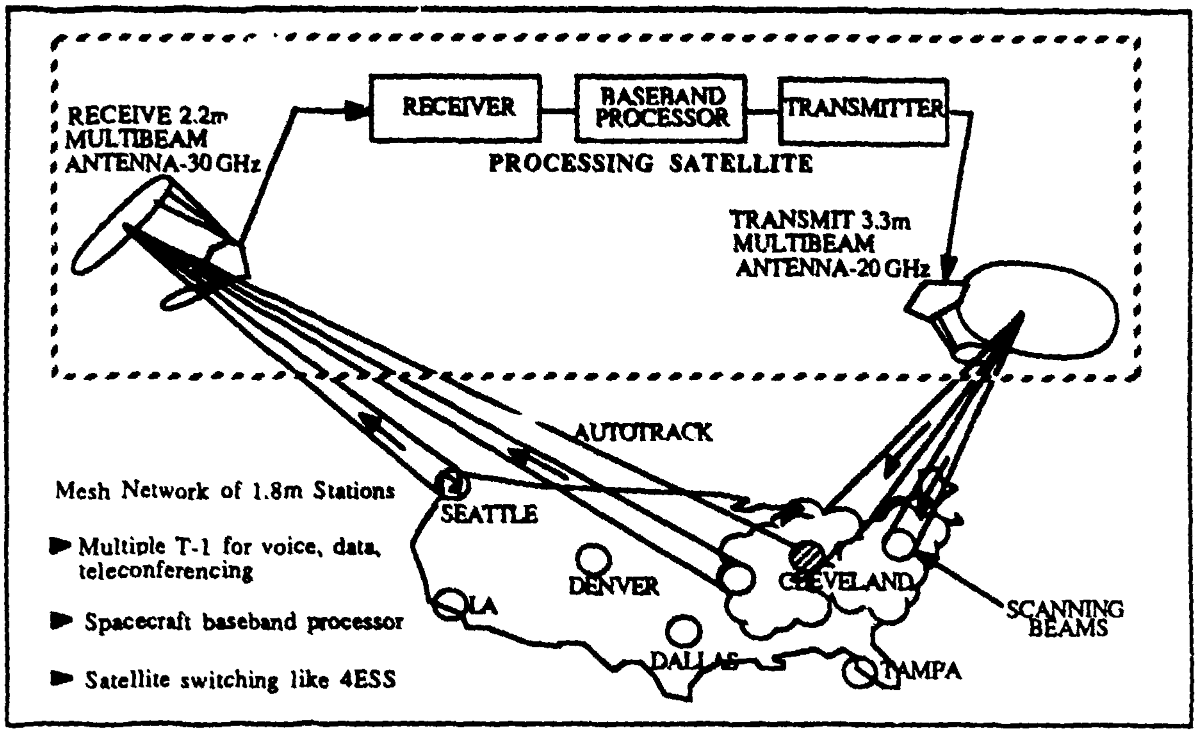


Figure 3.6 ACTS 30/20 GHz Experimental System (CPS Mode)
[Ref. 19: p. 2]

Each scanning beam will normally move to 10 different locations within its coverage area in a cycle. This cycle represents one frame in the TDMA scheme. This cycle, or frame, is one millisecond in length with the scanning beam able to move from one location, or dwell area, to another in one

microsecond. The remainder of the time in the cycle is used in receiving or transmitting information. This is the use of the TDMA structure previously explained in Chapter II. For ACTS, the downlink signal is pure TDMA, however for the uplink signal it may be a combination of FDMA and TDMA. As previously stated, the LBR system operates at a maximum data rate of 110 Mbps per beam or it may be segmented into four 27.5 Mbps channels. This is possible by using FDMA within the TDMA scheme of the scanning beams. In other words, each of the four 27.5 Mbps channels is operating at different frequencies (FDMA) within the same spectrum of the one 110 Mbps channel. This will significantly increase the number of users who have access to the satellite. Figure 3.7 shows the uplink beam FDM/TDM organization. The message bursts shown in Figure 3.7 are a function of the

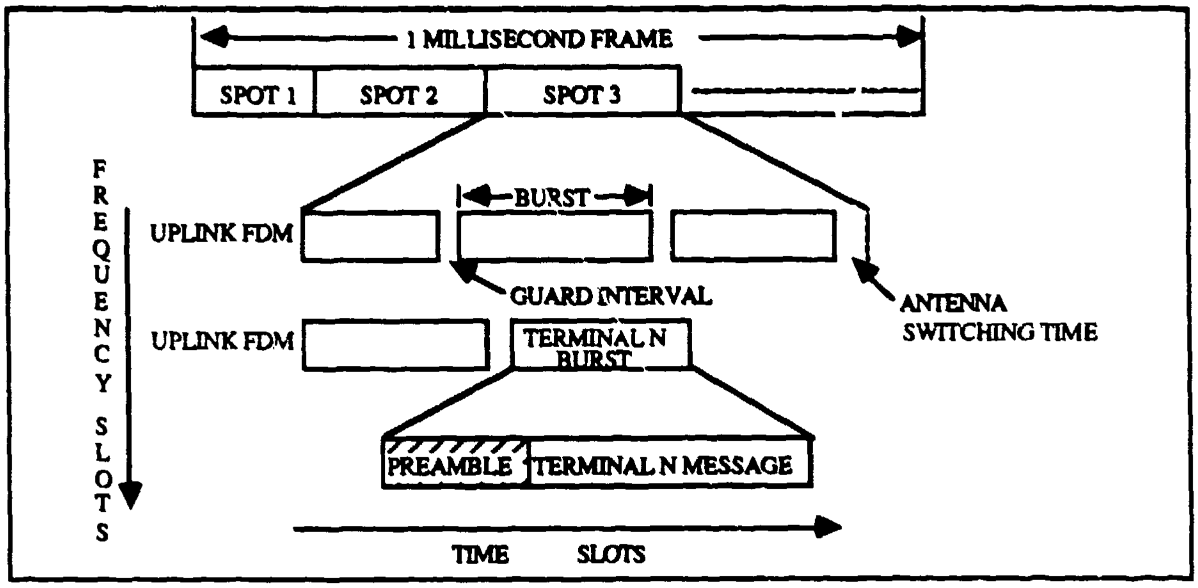


Figure 3.7 Uplink Beam FDM/TDM Organization [Ref. 29: p. 673]

user traffic demands. These bursts may vary from one slot within the dwell period up to the entire frame time of one millisecond. Each of the message burst lengths is adjusted according to the user's requirements. This assignment of burst time based on need is referred to as demand assigned multiple access (DAMA). Therefore, as the scanning beam moves from area to area, the users in each area transmit their traffic in short bursts as a time

share user. They are using the same frequency as other users in their area but a different slot in time to prevent interference. The FDMA users are using those same time slots as other users but at different frequencies. In addition to the increase in the number of users possible, the FDMA/TDMA requires lower TDMA burst rates which benefits the use of lower power small terminal transmitters. [Refs. 24: p. 200; 29: p. 673]

Working in conjunction with the scanning beams is the heart of the ACTS system, the onboard baseband processor. The processor for the ACTS is being built by Motorola Inc. and can be compared to the current electronic circuit switch that is used by AT&T, i.e., a 4ESS switch, in their terrestrial systems. The 4ESS switch is the backbone toll switch in that network. This means that the processor will take the uplink signal burst from the ground terminal, break it down into individual message elements by their destination, store the information, and then at the appropriate moment send the elements to the correct downlink path. The baseband term refers to the break down of the signal to the individual circuit level so switching may occur. The routing switch in the baseband processor is an 8x8 high speed nonblocking switch which, for the purposes of the ACTS experimental program, is connected as a 3x3 switch. Nonblocking means that there is a path out for every path in, therefore no block of traffic can occur. The data traffic passes through any of the three input ports to the outlet ports at a rate of 110 Mbps. The maximum rate permissible through the switch is 220 Mbps, a system requirement not a switch limitation. [Ref. 29: p. 674; 19: p. 2]

The third key element in the effective use of the LBR mode is the ground terminal. A critical factor in the success of the ACTS application is the ability to put small low cost, high data rate, ground terminals directly on the customers' premises. As discussed before, the gains of the narrow scanning beam permit the use of smaller ground terminals to achieve high data rates. This makes possible the use of these terminals at a variety of locations thereby forming a network of proliferated ground stations that bypasses the local terrestrial network. Table 3.4 shows the three basic ground terminals for ACTS in the LBR mode.

The fourth critical technology that the ACTS program will incorporate is that of intersatellite laser links. The laser links will be evaluated to support the concept of dynamic data transfer between satellites based on traffic destination requirements. The future goal is for distributed switching among satellites much as it is done in terrestrial systems. The distributed switching would cause minimal delay and avoid the relatively lengthy delays of double hopping between ground connected satellites, as illustrated in Figure 3.7. Two Gbps data rates are possible between satellites with the current laser components that are sized for satellites [Ref. 14: p. 5].

TABLE 3.4 TYPICAL ACTS GROUND TERMINALS
[Ref. 30: p. 2]

SATELLITE ROUTING MODE	TYPE	ANTENNA DIAMETER (METER)	CAPACITY	UPLINK/DOWNLINK BURST RATE MBPS	ACCESS
BASEBAND PROCESSOR VIA TWO HOPPING BEAMS	MICRO-1	1.8	1 TO 24 EVC	27.5/110	TDMA
	LBR-2	3.0	1 TO 48 EVC	55/220	TDMA
	LBR-1	5.0	1 TO 96 EVC	110/220	TDMA

EVC - 64 KBPS EQUIVALENT VOICE CIRCUIT

To explore this concept on the ACTS, a laser link will be tested as depicted in Figure 3.8. Although geosynchronous earth orbit (GEO) to GEO laser interconnects will not be tested, the GEO/LEO links with the Shuttle will provide information for evaluation of system performance. The tests will also provide information for future LEO/LEO links as well as links from the future Space Station to other orbiting platforms. Data from the shuttle sent by laser can be returned to the shuttle by laser or sent to ground by the radio frequency (RF) or laser downlinks. Data from the ground will go to ACTS via the RF link and to the shuttle by laser. The laser will be a 220 Mbps duplex laser. Duplex means that traffic may be passed both ways

simultaneously. The data rate from ACTS to the shuttle will be 50 Mbps but 220 Mbps on the return link. [Ref. 8: p. 13]

The previous paragraphs in this section have discussed the ACTS satellite and four key technologies in a much simplified manner. A greatly detailed look at the many complex systems which comprise the ACTS program is beyond the scope of this thesis. Those areas discussed are key to the ACTS concept and further discussion within this document. As previously noted, more detailed information on the ACTS may be found in the Appendix and the references. The next section will present a brief scenario of the ACTS concept applied in the commercial environment.

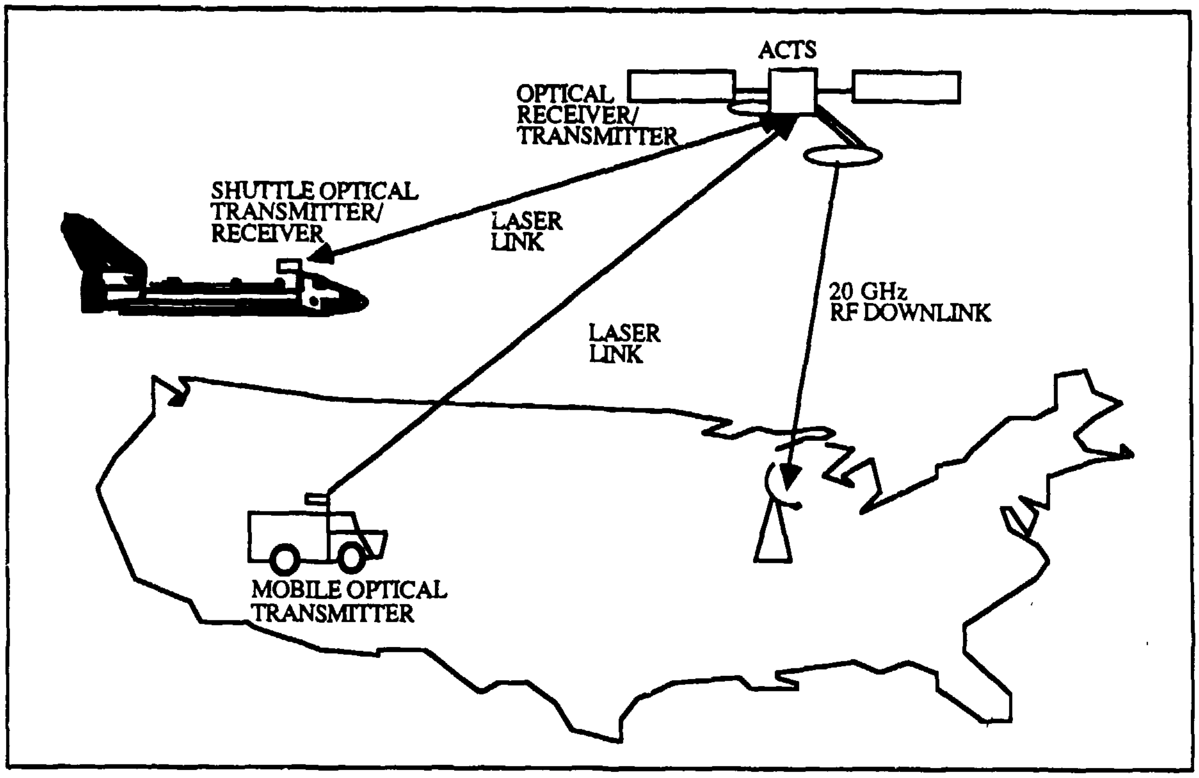


Figure 3.8 The ACTS Optical Intersatellite Links [Ref. 8: p. 13]

C. AN ACTS BASED COMMERCIAL SCENARIO

The next few paragraphs will briefly look at the application of the ACTS concept in a commercial based scenario. The intent will be to show how the technologies highlighted in the previous section may be applied in a business application. The basis for this discussion will be Dr. Braham's paper,

Improved System Cost and Performance Using ACTS Multi-beam Processing Satellites [Ref. 19]. Dr. Braham's paper discussed an Operational ACTS (OACTS) system as opposed to the experimental ACTS system previously described. An Operational ACTS (OACTS) system will be assumed within the context of this discussion with the greatest difference being the scaled up capability of an operational satellite. Any other assumed differences between what was previously described and the OACTS system will be noted as they occur. An in-depth detailed discussion will not be presented here but rather an illustration of the concept.

As previously mentioned, the VSAT concept of many remote stations exchanging traffic with a central node has been gaining acceptance among many large corporations. However, the concept falls short of optimizing the communications possibilities for voice circuits, low cost terminals, or high speed data rate. The OACTS addresses these issues and ushers in a competitive satellite environment. The 4ESS switch was also previously described as AT&T's primary switch for its backbone terrestrial network. The 4ESS will be used here as a basis of comparison to the OACTS.

The OACTS system would probably employ several thousand transmit/receive stations in a full up system. However, for the purpose of this scenario, 1024 stations will be assumed to parallel the capacity of the 4ESS. A block diagram of the OACTS is shown at Figure 3.9. These 1024 stations are small (1.8 meter antenna) earth terminals capable of T-1 data rate for voice, video conferences, and high speed data. They are spread across the U.S. covered by the 100 OACTS spot beams required to cover that area [Ref. 19: p. 2].

Corporations A and B have 200 stations each that are located throughout the U.S. They each have information to pass among any of their respective corporation's stations or to any of the other corporation's stations. Each of the stations can transmit information to multiple receive stations at the same time. For instance, a station of Corporation A may be transmitting a number of voice conversations, each routed to a different receive station. The satellite stores the received information after scanning all 1024 stations. The information is broken down by the baseband processor then collected into a packet of information for a particular station. Therefore, if Corporation A

stations in California and New Mexico are sending traffic to a Corporation B station in New York, the information is collected in the packet destined for that terminal. If the Corporation B station is not the only station in that spot beam getting traffic, each station is transmitted to sequentially in the assigned TDMA format. The spot beam is then moved to the next area and packets are transmitted as required to the receiving stations. This downlink process is continued through the 1024 stations until all previously received and stored

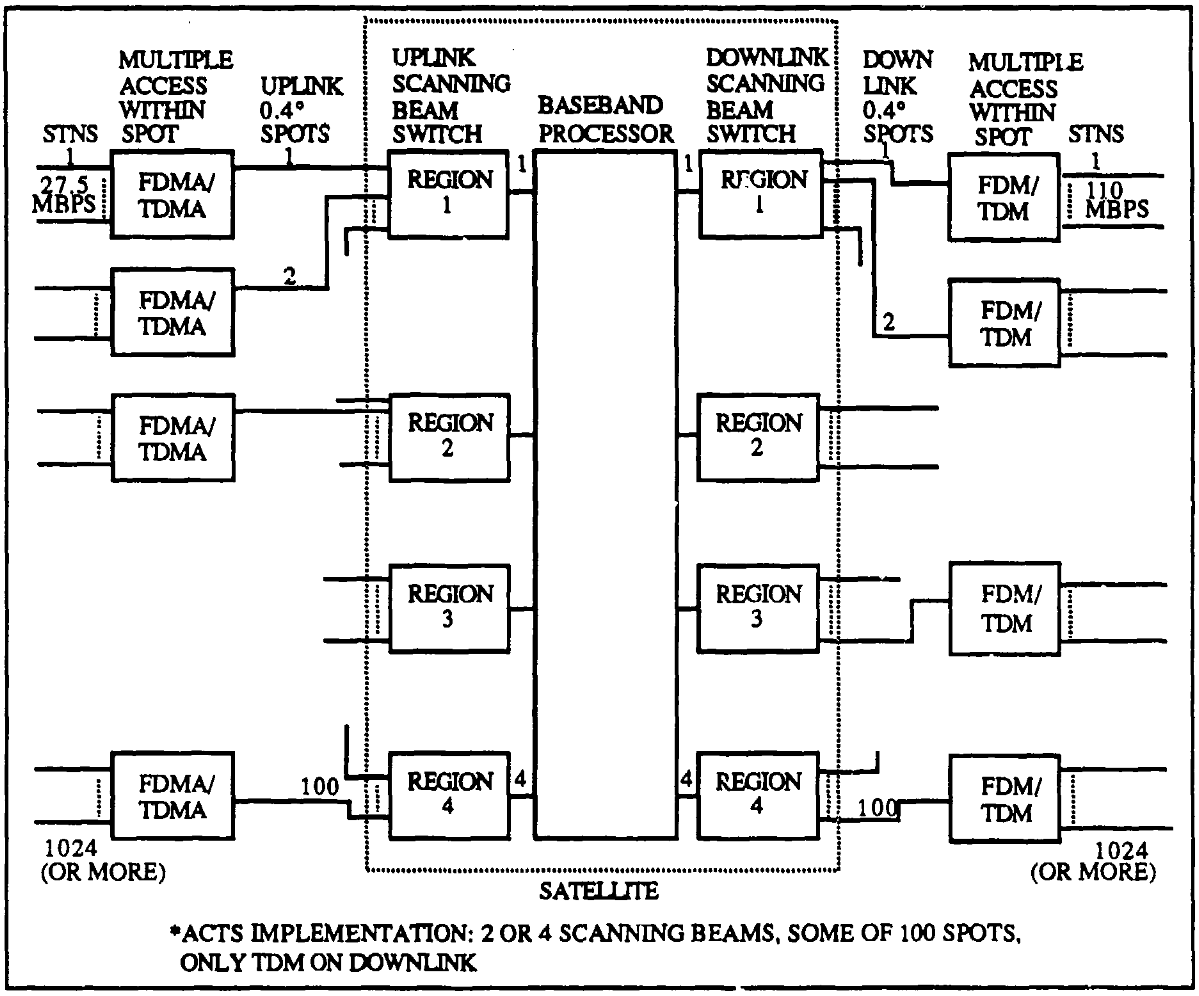


Figure 3.9 System Functional Block Diagram (Operational ACTS)*
[Ref. 19: p. 3]

data is transmitted. The receive/transmit process is repeated making the 1024 stations fully interconnected among all users. The switching operation

described for the OACTS is similar to the 4ESS switch. Figure 3.10 shows the functional block diagram for the 4ESS. Each input/output line (read as station for OACTS) has 105 different TDMA channels (read as TDMA slots for OACTS) which can be routed to any other channel. The OACTS works as a *switchboard in the sky*. [Ref. 19: pp. 2-3]

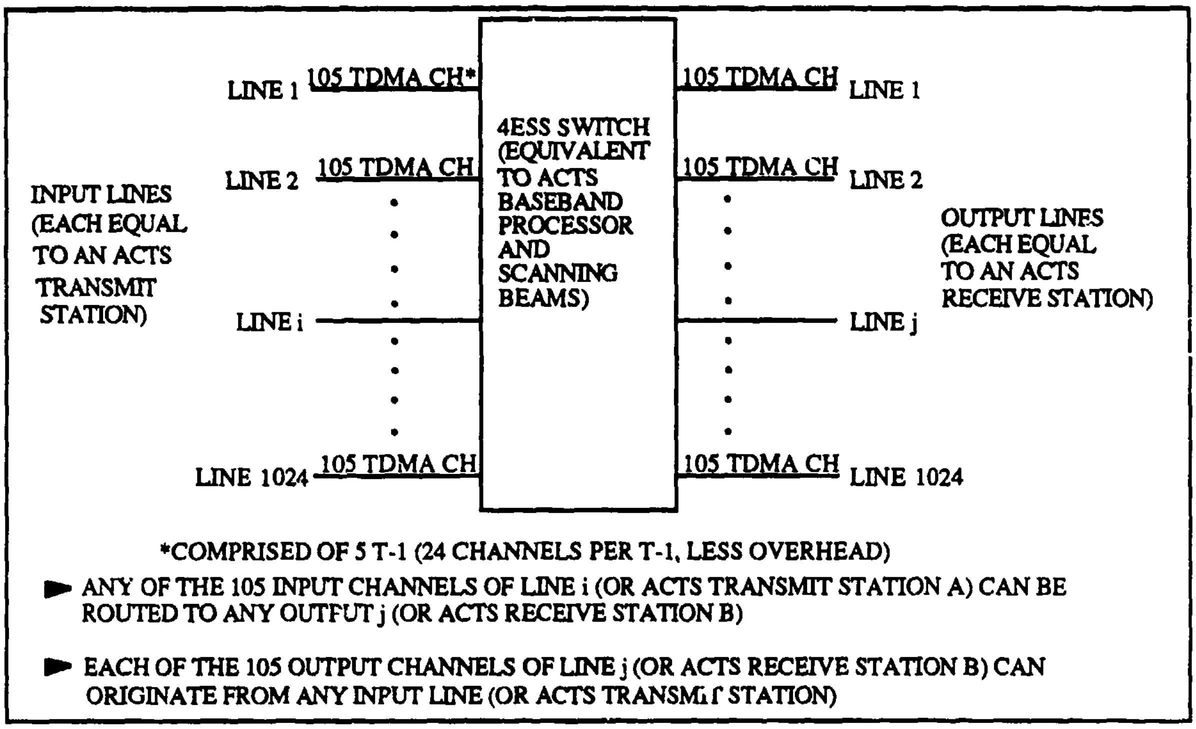


Figure 3.10 4ESS (and Equivalent in ACTS) [Ref. 19: p. 4]

This chapter has examined the ACTS program, highlighting several key technologies and discussing a brief scenario on its use. As previously discussed, the intent is to provide a look at capabilities and not get involved in great detail. Up to this point, it is hoped the reader has attained a basic understanding of satellite communications, the present state of the satellite communications industry and the role that ACTS may play in revitalizing the satellite industry. The next chapter will examine a specific government communications network, the Defense Data Network (DDN), its future evolution into a comprehensive worldwide data network, and the possible role that ACTS could play in its future.

IV. THE DEFENSE DATA NETWORK (DDN)

This chapter will provide basic information on the DDN to include background information, an overview of the DDN technology and a brief look at the operational concept for the DDN. As with previous chapters of this thesis, a detailed discussion of the technology components and procedures will not be attempted here. The discussion will involve general concepts and operational information. The object will be to provide basic information that may be combined with information presented in previous chapters for further discussion. Prior to discussing the DDN, a brief discussion of packet switching, on which the DDN is based, will be provided.

A. WHAT IS PACKET SWITCHING?

Packet switching is based on the concept that a length of information bits representing a message can be comprised of many small packets of information bits. Figure 4.1 is used as an illustration. A message is entered into the system from a user or a computer host, in this case called the source computer. The message goes from the source computer to the packet switch. At the switch the message is stored temporarily until the switch is prepared to transmit. While processing the message, the switch divides the message into packets of bits, each packet the same size. The size of the packets may vary from network to network. The DDN uses packets of 1008 bits. The packets are themselves individual messages with the required information to get them to their destination switch. The switch determines the proper routing for the packets and sends them to the proper switches. Each packet sent between switches is acknowledged (ACK) by the receiving switch. In the diagram the tandem switch refers to the relay function of the switch in passing the packets. At the destination switch the packets are reassembled into the original message and forwarded to the destination computer. The destination switch acknowledges the receipt of the message by sending an ACK back to the source computer. The ACK takes the form of a request for next message (RFNM) as the system operates on the assumption that another message will

follow along the same circuit. An inability to deliver a message, due to missing packets or some other system failure, will cause the incomplete message to be returned to the source computer. If the source computer does not receive either an RFNM or an incomplete message back within some established time period then the message will be retransmitted. [Ref. 31: pp. 110-111]

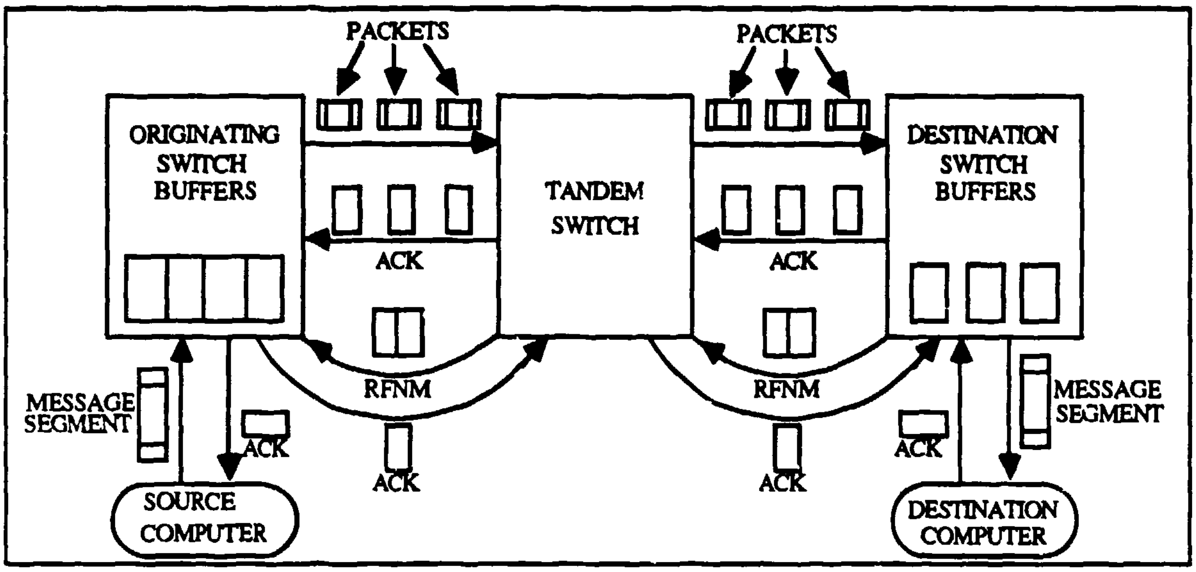


Figure 4.1 Operational Model of an ARPANET-like Network [Ref. 31: p. 76]

There are three basic ways of routing traffic in a packet-switched network. These routing techniques are all software tools that manipulate the switches to make the system function. The three routing techniques are packet flooding, random routing, and directory routing. Because random routing is not frequently used and is not used in the DDN it will not be further discussed here. Packet flooding is a routing technique where every possible path between the originating switch and the destination switch is used to move packets to their destination. Duplicate packets are placed in the system and transmitted to the receiving switch. As a packet arrives at any intermediate switches it is again transmitted on all available paths, thus flooding the network. Messages are assembled as the packets arrive at the destination switch and the excess packets are discarded. The use of this

technique, however, significantly increases the amount of traffic on the network, and as the network size increases so does the traffic load. This technique provides a very robust system and is used in some military applications. Procedures for decreasing the load on the system while using this technique have been devised. [Ref. 32: pp. 180-181]

Directory routing is the most frequently used of the three techniques. The directory technique uses a table, or set of instructions, that tell the switch where to transmit incoming traffic. The directory may have knowledge only of switches immediately adjacent to it, or its knowledge may encompass the whole network. These are known as partial-path or full-path directories, respectively. The full-path directory enables the switch to determine the shortest path to the destination based on its current knowledge of the network. The most flexible of the techniques within this category is adaptive or dynamic directory routing. The switches are continually updated on the status of the system and can select the shortest path to a packet's destination for each packet that enters the switch for transmission. The DDN uses this type of routing technique. [Ref. 32: pp. 180-181, 185-186]

B. BACKGROUND

The evolution of the DDN first started in 1969 as a research and development project managed by the Department of the Defense (DoD). The program was directed by DoD's Advanced Research Projects Agency (ARPA), now known as the Defense Advanced Research Projects Agency (DARPA), and was the forerunner of present day packet switching networks (civilian or military). The network was labeled the ARPANET. The ARPANET was originally devised as a network with an experimental purpose. The network connected a wide variety of users, primarily across the U.S., with its principal role being that of a development tool for state-of-the-art advances in computer resource sharing. The network provided the sharing of hardware, software, and data resources through the efficient use of computer communications across a broad range of users. As the experimental nature of the network progressed, it also became a much used, effective system for those customers with operational requirements. Because of the increased use of the network by operational users, the

responsibility for system operation was transferred from DARPA to the Defense Communications Agency (DCA) in 1975. [Ref. 33: p. 2]

In late 1981 the Director of the DCA tasked a design team to examine the possibility of developing an ARPANET-based system as a replacement for the AUTODIN II system. AUTODIN II was the second phase of the Automatic Digital Information Network (AUTODIN). AUTODIN provides the capability for the U.S. government to pass message traffic worldwide. AUTODIN is a message switching network, as opposed to packet switching, therefore each message is stored in its entirety before being passed to the next switch. This method of handling the data constitutes a basic difference from the ARPANET and was a key point on which the study focused. As a result of the study, Deputy Secretary of Defense Frank Carlucci, on 2 April 1982, directed that the DDN be developed as a replacement to the AUTODIN II program. The AUTODIN II program was terminated with the issuance of Mr. Carlucci's directive and the DDN began its evolution into the primary data system for the DoD. The initial plan reflecting the development of the DDN was the Defense Data Network Program Plan published in January 1982 and revised in May of that same year. [Refs. 31: p. 29; 34: pp. iii-v]

The ARPANET was initially divided logically in 1983 and then physically in 1984 into the ARPANET and the MILNET (Military Network). This represented the two basic users of the network with the ARPANET remaining essentially a research and development network and the MILNET an unclassified operational military network. Figure 4.2 depicts the eventual evolution of current or planned data networks into the DDN. The development of the classified segment of the DDN will result from the use of end-to-end secure devices that will allow higher classification level traffic to ride the secret backbone. The interconnection of the networks will provide more capability for the classified segment and will be controlled by one-way gates to prevent a possible comprise of classified material. Eventually, the fielding of National Security Agency (NSA) communications security equipment, known as BLACKER, will allow for a single fully integrated multilevel secure network. [Refs. 33: pp. 2-3; 35: p. 2-3]

The single packet-switching network envisioned in the 1982 DDN Program Plan was comprised of 171 packet switches spread over 85 geographical locations and serving 488 hosts and 1446 terminals. Hosts are those computers that use a packet switching network to communicate. However, the DDN in 1982 included three different segments, the

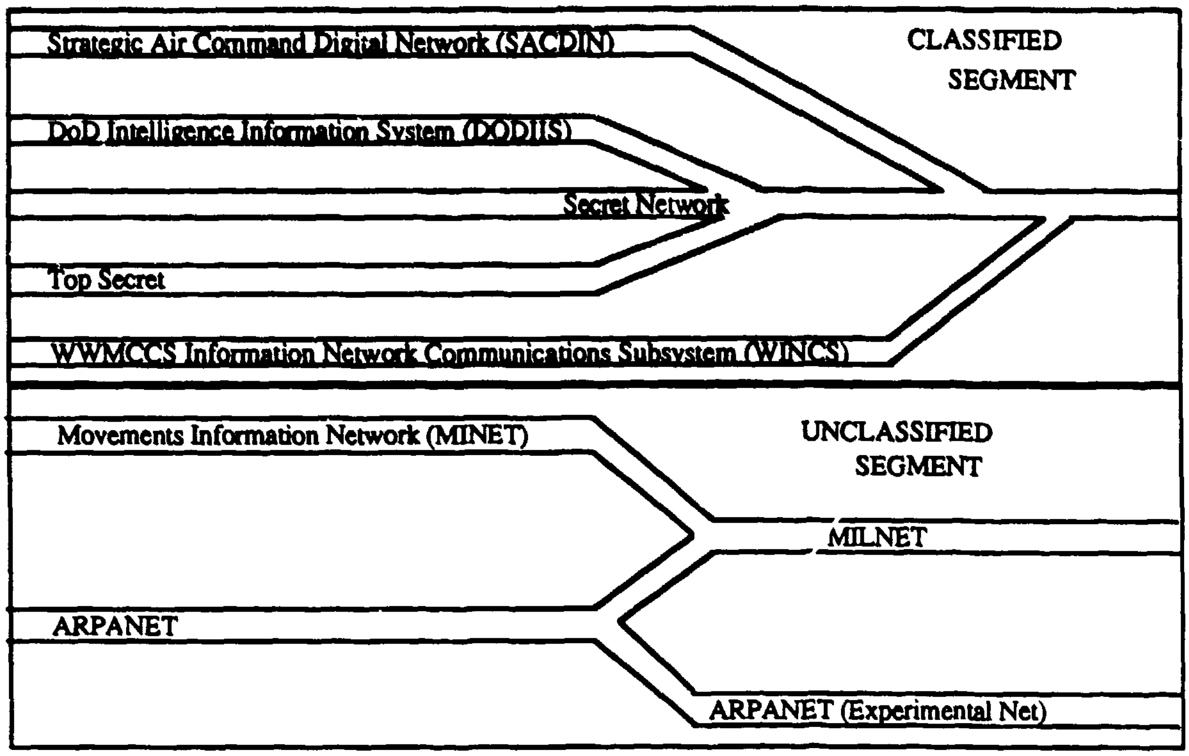


Figure 4.2 The DDN Evolution Strategy [Ref. 33: p. 3]

ARPANET, the MINET and the WIN (or WINCS). The ARPANET was made up of approximately 100 packet switches and served research requirements and unclassified DoD requirements. The MINET was a logistics network for Europe, consisting of 12 packets switches and was being installed in 1982. The WIN, the only part of the DDN which handled classified traffic, was comprised of 17 packet switches and was the data system for the World Wide Military Command and Control System. The split of the ARPANET in 1984 into the ARPANET and MILNET apportioned the switches 40 and 57 respectively. As previously mentioned, the MILNET absorbed the MINET, also in 1984, and by October 1985 had

grown to 100 packet switches worldwide supporting 300 operational users and moving over 14 million packets per day. [Ref. 36: pp. 9-10]

Upgrades to the various networks in Figure 4.2 are projected with the MILNET expanding to an estimated 174 switches connected by more than 300 trunks. Further expansion of the MILNET is planned with an increase of packet switches in Europe to 44 by the end of 1987. The expansion of the classified systems in Figure 4.2 is also proceeding toward the unified system but will not be further described here. [Ref. 36: p. 16]

C. THE DDN SYSTEM

As a basis for further examining the DDN network, it is necessary to understand the major components that comprise the system. Figure 4.3 shows the components of the DDN system. In the following paragraphs, a brief description of the components will be stated to further familiarize the reader with the system operation.

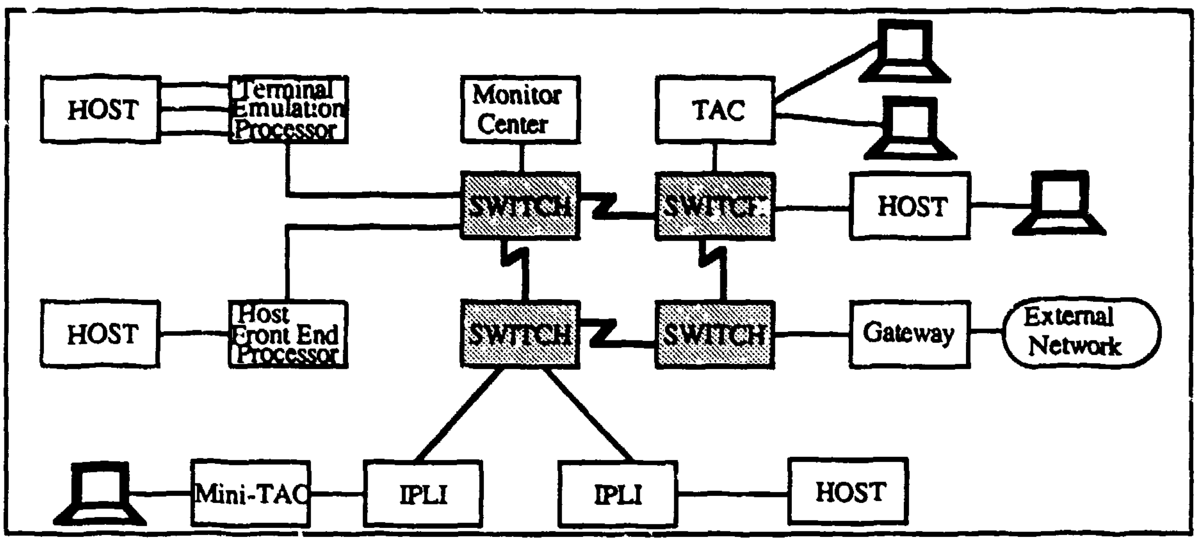


Figure 4.3 DDN Components [Ref. 33: p. 7]

The backbone of the network are the packet switches. The packet switch currently used on the DDN is the C/30E packet switch manufactured by the BBN Communications Company. A fully compatible upgrade to the C/30E, the C/300, is being developed which will have double the capacity of the C/30E. The C/30 was the packet switch being used on the ARPANET when

the DDN was organized. Therefore, changes to the switch for use on the DDN were minor. The C/30E or C/300 are normally connected to three other packet switches in the network. [Refs. 36: p. 46; 34: p. 3] The capability of the packet switches is largely determined by the operating system software of the switch. As an illustration, the user traffic rate capacity of a full subnetwork (256 switches), of which the DDN is made up of five, increases from 5.9 Mbps to 10.2 Mbps with the change in operating system software from Packet Switching Node (PSN) Release 6 to Release 7 [Ref. 36: pp. 43, 46]. This is without hardware improvements. The C/30E can support up to 38 devices and the C/300 will be able to support approximately 58 devices. This capability assumes that each switch is also linked to three other switches. [Ref. 36: pp. 4-5, 46]

Another important component of the DDN system is the host. The host is linked to the network through the host interface device (HID). In Figure 4.4 the three interfacing options for the hosts are highlighted. The direct link

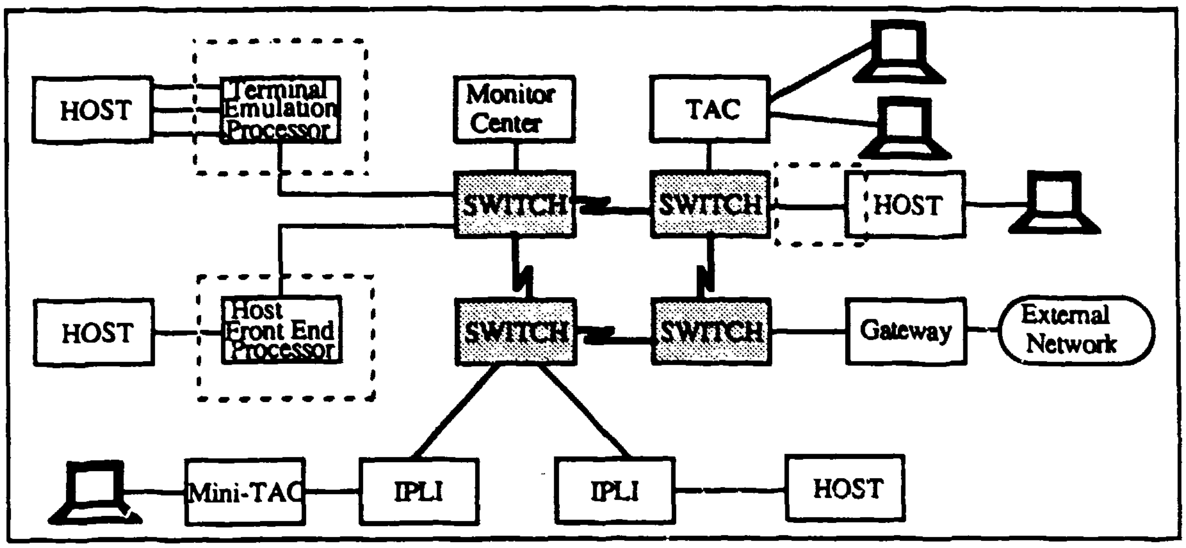


Figure 4.4 Interfacing Options for the Host [Ref. 33: p. 7]

from host to switch (highlighted) indicates the use of the HID as the hardware interface with the host providing all the required protocols for operation. The Host Front End Processor (HFEP) option uses a front end processor with the host computer. The front end processor runs the protocol software for

network operation instead of the host as above. The third option, the Terminal Emulation Processor (TEP), attaches to the terminal ports of a host and also to a switch. In this configuration, the host can only see the network as locally attached terminals and not use the full capability of the system. This approach is not recommended except for special circumstances. The host may be colocated with the switch or linked by a communications circuit from a remote location. [Ref. 34: pp. 48-58]

The Monitoring Center (MC) from Figure 4.3 is a computer providing the system overwatch for a portion of the network. The MC continuously monitors information provided by network components to assess the system status, topology, and throughput, as well as other information. The MC also controls the system by being able to access components and make changes in configuration, isolate faults and diagnose problem areas, and perform software maintenance. The MC also acts as a database management facility for the network. [Ref. 34: pp. 59-60]

The Internet Private Line Interface, (IPLI), shown in Figure 4.3, is a security device. The device consists of three components, two packet processors on either side of a cryptographic device. The IPLI allows the interface of those hosts requiring protected systems into the mainstream system. [Ref. 34: pp. 39-40]

The Terminal Access Controller (TAC) and the min-TAC are interface devices that allows for the interface of a terminal with the network. The only difference is in the terminal number capacity, for instance, the mini-TAC capacity is 16 terminals, while the TAC's capacity is 63 terminals. All terminals entering from a TAC or mini-TAC are multiplexed onto the same communications circuit that links the TAC to the switching node. Terminal data rates supported by the TACs are from 110 to 9600 bps for direct line hookup or if dialing up, rates are from 110 to 2400 bps. On the other side of the TAC to the switch, possible transmission rates are from 9600 to 56000 bps. [Refs. 34: pp. 42-43; 24: p. 4]

D. DDN SYSTEM OPERATION

After the preceding brief discussion of the components of the DDN system, Figure 4.5 is shown to discuss DDN system operation. As previously

discussed, the DDN is segmented into two basic categories of classified and unclassified users. Figure 4.5 shows a block diagram of these two segments and how they interface. DES and KG, from the figure, represent encryption devices. DES (Data Encryption Standard) corresponds to commercial encryption techniques and is used on all interswitch trunks in CONUS for the unclassified network. KG (Key Generation) designates those devices that are military grade encryption certified and are used for encryption on the classified network and on all trunks leaving or external to the continental United States (CONUS) regardless of the network. The protection of traffic within the DDN is provided by link encryption and end-to-end encryption. Link encryption provides the basic security level protection across the whole

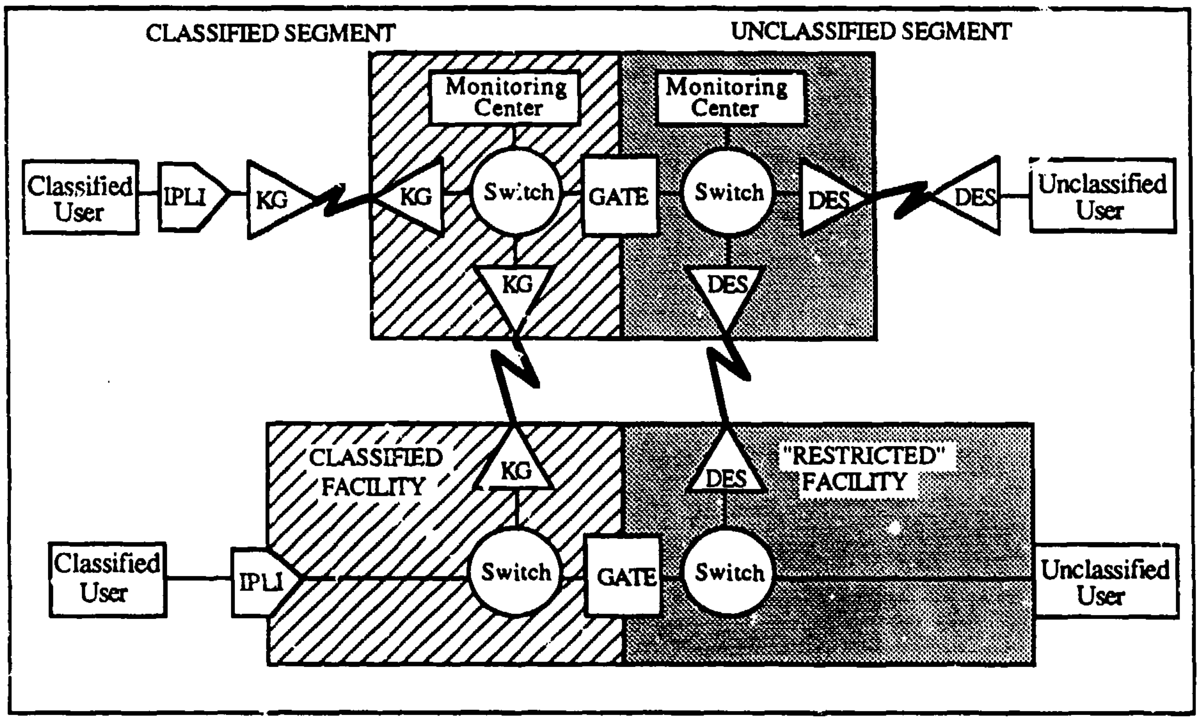


Figure 4.5 Segmented DDN [Ref. 33: p. 7]

system. End-to-end encryption provides for additional security by normally encrypting particular circuits at a higher level of classification. The gateways depicted on the diagram will allow the usage of the large unclassified network by classified users, but not vice versa, if the situation requires it. [Ref. 33: pp. 7-8]

The performance of the DDN is measured by its ability to meet the needs of the users who require data services. The transmission time, system availability, and survivability are key factors of performance that are part of the DDN operation. The subdivision of the inputted data into packets, switching the data through the network, and the assembly of the packets for the data do not present a major increase in the service time. This time accounts for a small portion of the waiting time experienced by an interactive user. Those interactive systems connected to the DDN are expected to experience an increase of only about 200 milliseconds in response time from that experienced with systems connected by dedicated, long haul circuits. [Ref. 33: p. 5]

> The average end-to-end delay for transmission of a high priority packet across the DDN backbone is about 90 milliseconds, with 99 percent of all packets being transmitted within approximately one-half second. Using transoceanic satellite circuits increases these figures by about 300 milliseconds. Thus, DDN effectively supports query/response and interactive applications as well as batch or record transmissions. [Ref. 33: p. 5]

The availability of the system for network users is one success measure of system operation. The DDN is designed so that at least 99% of the time a single-homed user (user having access to one switch) will have access to the network when it is desired. To further increase this percentage, users may be dual-homed from separate switches and their availability rate will increase to 99.9%. This level of availability is critical to the successful operation of the network. The preceding three paragraphs provided information to familiarize the reader with the expected capabilities of the system. Variations may be experienced based on system maturity and/or traffic load. [Ref. 33: p. 6]

Survivability of the DDN is of paramount importance due to criticality of communications networks that comprise the DDN. A major survivability feature is the robustness of the system in terms of number of nodes and trunks. Additionally, the packet switching concept itself increases survivability through its use of adaptive routing and multiple paths. It also

incorporates three additional features to enhance the survivability of the network. These features are network equipment facilities that are as survivable as the user's facilities they are supporting, a redundancy of critical equipment and circuits, and a graceful degradation of service if system damage is sustained. Graceful degradation refers to the system's ability to adapt to changes in network connectivity as a result of switch or circuit failure and route the traffic through alternate paths to its destination. [Ref. 33: pp. 6-7]

This chapter has provided a brief overview of the DDN network. The discussion of the network's evolution, components and some basic operational features is to provide a basis for further discussion of the DDN and its possible use with ACTS in the next chapter.

V. THE ACTS AND THE DDN -- A DISCUSSION

A. OVERVIEW

Previous chapters have provided the reader with background information on satellite orbits and communications engineering concepts, the evolution of today's communications satellites, future communications satellite technology and a brief look at the packet switching DDN. The intent was to give the reader a basic foundation of knowledge so that a discussion using the information provided could take place. Therefore, this chapter discusses the emerging ACTS system and its application to the DDN system. As previously mentioned, this document is not written to an engineering level of detail but rather emphasizes broad concepts. The following paragraphs briefly state some assumptions made for discussion purposes, evaluate several concepts employing the ACTS system with the DDN, and provide a brief discussion of communications security (COMSEC) considerations.

B. ASSUMPTIONS

The ACTS program is experimental in nature and therefore subject to constant changes in the development and operation of the system. These changes will occur not only in the experimental program, but in the operational ACTS system as well with some changes already projected. Two examples are cited as illustrations. First, a telephone conversation with Mr. Gary Zarlengo, NASA ACTS Program Experiment Manager, on 13 March 1987 [Ref. 37] indicated that there may be a change in the antennas used in the experimental program. The change would be to use 2.44 meter (m) and 3.47 m antennas instead of the 1.8 m and 3.0 m antennas. Secondly, in Dr. Braham's article, *Improved System Cost and Performance Using ACTS Multi-beam Processing Satellites* [Ref. 19], he discusses the operational ACTS with 16 or 32 Kbps channels for voice traffic instead of the 64 Kbps channels used in the experimental ACTS. For the purposes of discussion here, the earth station will be assumed to have a 1.8m antenna and a capability of up to the T-1 capacity of 1.544 Mbps. Since data will be the

basis for our discussion, the difference between 16, 32, or 64 Kbps for the voice channels will not be discussed. The operational ACTS channel will be assumed to carry a data rate from 9600 bps to 56,000 bps [Ref. 19: p. 6].

The cost of the ACTS ground terminal will be taken from Dr. Braham's 1986 article referenced above and is assumed to be $25,000 per station. Dr. Braham indicated in discussions on 14 January 1987 [Ref. 27] and 16 April 1987 [Ref. 38] that a rough estimate for the cost of leasing a 16 Kbps circuit on the operational ACTS is projected at $600 per month for unlimited usage. Dr. Braham further stated that, as rough cost estimates for other data rates, scaling with relation to the 16 Kbps circuit would be appropriate. For instance, if a customer desired a 64 Kbps circuit the estimated cost would be approximately $2400 per month.

As a comparison tool for some *rough* calculations, the DDN Baseline Cost Model referenced in the Bolt Beranek and Newman (BBN) Communications Corporation report, *Network Usage and Cost Sensitivity* [Ref. 39] will be used. The cost model was derived from the CONUS portion of the MILNET in 1986. This portion of the network has 131 nodes connected by 247 trunks. The baseline model total trunking costs are estimated at $607,468 per month. The 247 trunks are divided into three groups with 159 of the 56,000 bps digital trunk lines, 25 of the 9,600 bps digital trunks line and 63 trunks that are the more expensive 50,000 bps wideband analog lines. The topology used in the cost model excluded portions of the MILNET outside CONUS due to widely varying trunking costs from country to country and a difference in peak hours from CONUS stations due to time differences. The topology also represented a network that ensured that between any two nodes there were at least two independent paths. This breakout of nodes and trunks will be used for all discussions unless otherwise stated. [Ref. 39: p. 39]

The costs discussed above will be used in the following paragraphs to provide a basis for "rough" comparisons of the costs of operating an ACTS application with the baseline model. It should be emphasized that these comparisons are general in nature and can only show orders of magnitude comparisons. The numbers estimated by Dr. Braham are projected by him based on his research and may be subject to change. Therefore, a much more

detailed analysis would have to be completed to ensure all costs are accounted for before a comprehensive conclusion could be reached. That is not within the scope of this effort. Since both reports were published in 1986, the assumption will be made that all dollar figures are in 1986 dollars and an adjustment is not needed for comparison.

C. APPLICATION CONCEPTS

This portion of the chapter will examine the use of the ACTS system with the DDN by discussing several different application concepts. The approach will consist of outlining the application concept, doing some basic analysis of the concept and discussing the advantages and disadvantages of the concept. From this approach, the reader will gain a basic appreciation for the applicability of the ACTS system to the DDN and its strengths and weaknesses. Advantages or disadvantages which are common to all applications will be discussed after all applications are examined.

The first application to be discussed will place an ACTS ground station at each switching node. For the purposes of discussion, the CONUS network will consist of the 131 nodes, the 131 ground stations, the hosts supported from the switches and the ACTS. Instead of each node being connected to several other switches, the node is linked to the ACTS through the ground station. Therefore, the node is connected to all other nodes in the network by a single hop. A message will enter the switch, be broken down into packets for the destination switch, transmitted at the appropriate time corresponding to the TDMA scheme to the satellite with other traffic, sorted and stored, and at the correct time the packets are downlinked to the appropriate ground station and node. This process is illustrated in Figure 5.1.

A brief discussion will follow on the basic costs of this application and the costs of the baseline model network. The reader will note that these calculations are used only for general order of magnitude comparisons not as a comprehensive analysis. The cost of equipping the 131 nodes with the earth stations is:

131 nodes x $25,000/node = $3.275 Million.

There is also the additional cost of leasing 131 56 Kbps trunks interconnecting the earth stations to the satellites. The cost of each circuit is

scaled from the $600 per month per 16 Kbps circuit. The scaled cost is approximately $2100 per month for unlimited usage. Therefore the monthly rate is:

131 circuits (ckts) x $2100/56Kbps ckt/month = $275,100.

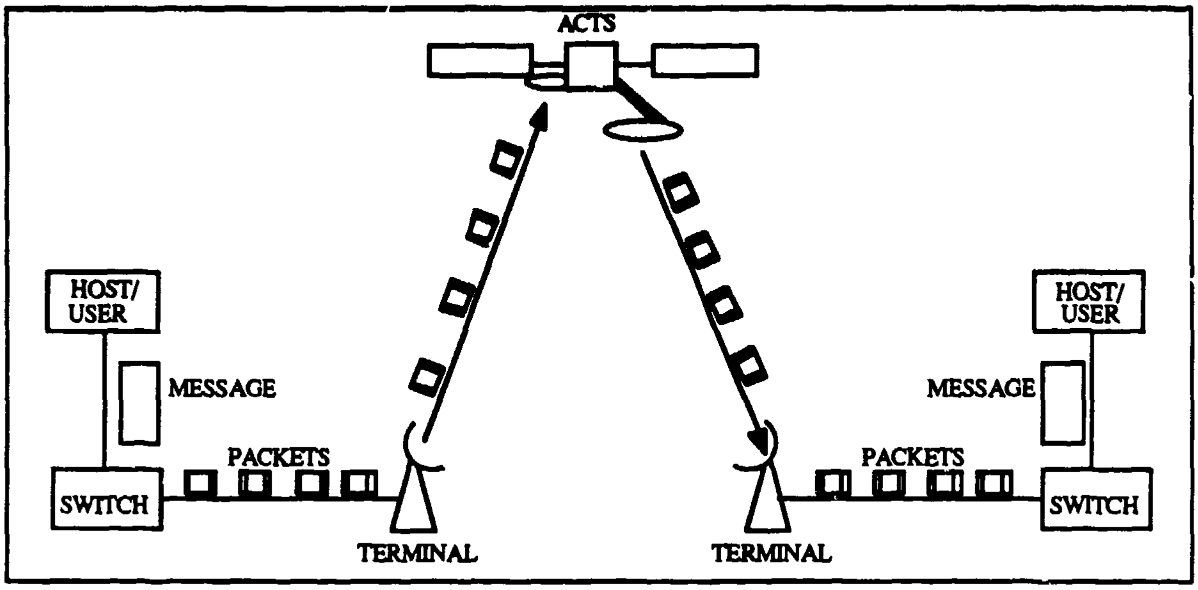


Figure 5.1 ACTS Used with the Current DDN System

This will provide high speed trunks to all nodes. A hypothetical first year cost for this system is determined from the following:

$3,275,000 + (12 months/year x $275,100/month) = $6,576,200.

This is the first year cost, subsequently the cost would drop to the yearly cost of leasing trunks, approximately $3,301,200. The monthly charge for the DDN in the baseline model to connect these 131 sites was $607,468 per month, for a yearly cost of:

$607,468/month x 12 month/year = $7,289,616.

The average number of trunks in the baseline model is approximately 2 trunks per node. If it is assumed that the connections are required for data traffic rather than for redundancy considerations then the data rate of the ACTS circuits can be scaled accordingly. Therefore, if the data rate is doubled for each station, providing a 112 Kbps capacity, the yearly cost would double also to $6,601,200, still less than the $7,289,616 figure. This

figure does not incorporate any operating costs for the ground stations which would add additional costs.

The $607,468 monthly figure represents a mixture of data rate circuits (i.e. 56 Kbps, 9.6 Kbps, 50 Kbps) over dedicated lines for the system connectivity. The ACTS system requires significantly less circuits to achieve the same connectivity. As previously stated, the numbers generated above do not establish the inherent superiority of the ACTS system to the terrestrial DDN system. There are many factors to be considered and a much more detailed analysis required to make a conclusive decision. The intent is to show that given these basic parameters of interconnectivity, the ACTS program should be examined further from a cost standpoint.

The following discussion will address some peculiarities of this particular application of the ACTS system. The above application, while providing a dynamic and effective data transfer system, does not effectively use the equipment involved. As the message enters the node from the host, the node creates the packets and routes them to their destination. In this case, there is only one route for each packet and that is to the satellite and then to the destination switch. Therefore, the node will address the packet to the destination switch and the satellite will deliver the packet at the appropriate time. If there is more than one satellite in the network (Dr. Braham believes that as many as 10 to 20 of the ACTS type satellites may be serving the U.S. in future years [Ref. 27]) then the node will determine the routing of the packet to arrive at its destination switch. This scenario is not a very effective use of the switch or the satellite. The satellite will become a fancy bent pipe that will connect two locations based upon instructions from the ground. The switch will not be fully utilized because its ability to route packets will be limited by the dynamic switching of the multibeam system and the limited size of the satellite network. The purpose of the ACTS program is to provide a switching platform in space, therefore the elimination of the ground switches and the absorption of their functions by the satellite would seem to be the next logical step.

This second application will discuss the elimination of the ground packet switches and the placement of the ground stations at the hosts. Therefore, the 131 nodes used in the previous example are eliminated. Each of the nodes is

assumed to have an average of 16 hosts assigned for a C30E switch [Ref. 40: p. 232]. Therefore, the total number of hosts in the system is:

131 nodes x 16 hosts/node = 2096 hosts.

These 2096 hosts would have their own ground stations with links directly to the satellite. The cost of the earth station for these hosts would be:

2096 hosts x 1 terminal/host x $25,000/terminal = $52,400,000.

In addition to this amount, the cost of a device at each host to assemble/disassemble packets as well as address them would have to be added. Assuming that 75% of these hosts are connected to the satellite by 9.6 Kbps circuits with the other 25% connected by 19.2 Kbps circuits. The additional yearly costs for 9.6 Kbps circuits would be:

2096 hosts x .75 9.6Kbps ckts/hosts = 1572 9.6Kbps ckts

1572 9.6Kbps ckts x $360/month/9.6Kbps ckt= $565,920/month

$565,920/month x 12 months/year = $6,791,040/year for 9.6Kbps ckts

and for 19.2 Kbps circuits:

2096 hosts x .25 19.2Kbps ckts/hosts = 524 19.2Kbps

524 19.2Kbps ckts x $720/month/19.2Kbps ckt= $377,280/month

$377,280/month x 12 month/year =$4,527,360/year for 19.2Kbps ckts.

therefore the total yearly cost is:

$4,527,360 + $6,791,040 = $11,318,40 per year.

The $11 Million and $52 Million, in addition to the cost of the devices to assemble/disassemble packets, make the startup costs of this application very significant. The number of hosts assumed may be higher if C/300 switches are used, thus increasing the total cost estimated. The deletion of 131 switches and their operating costs would probably not amount to much since the switches were already a sunk cost and the operating costs for the ground terminals would be an additional cost. An amount will not be estimated here; however, compared to the cost of equipping the hosts and the trunking costs this amount would probably be much smaller.

This application of the ACTS technology is very costly and may not be the most efficient use for the DDN. It is a more efficient application as far as the ACTS is concerned because the satellite is routing the traffic. The packets coming to the switch from the ground are routed by the onboard processor to their destination through one or multiple satellites. This effectively uses the

satellite but the allocation of the terminals on the ground may not be cost effective. The majority of the hosts today access a switch through direct attachment rather than over a communications link [Ref. 40: p. 211]. Therefore, ground terminals at every host may place many terminals in a relatively small area with many hosts requiring only relatively low data rates (9.6 Kbps or 19.2 Kbps). This may not be an effective solution from a cost point of view. Figure 5.2 depicts this concept.

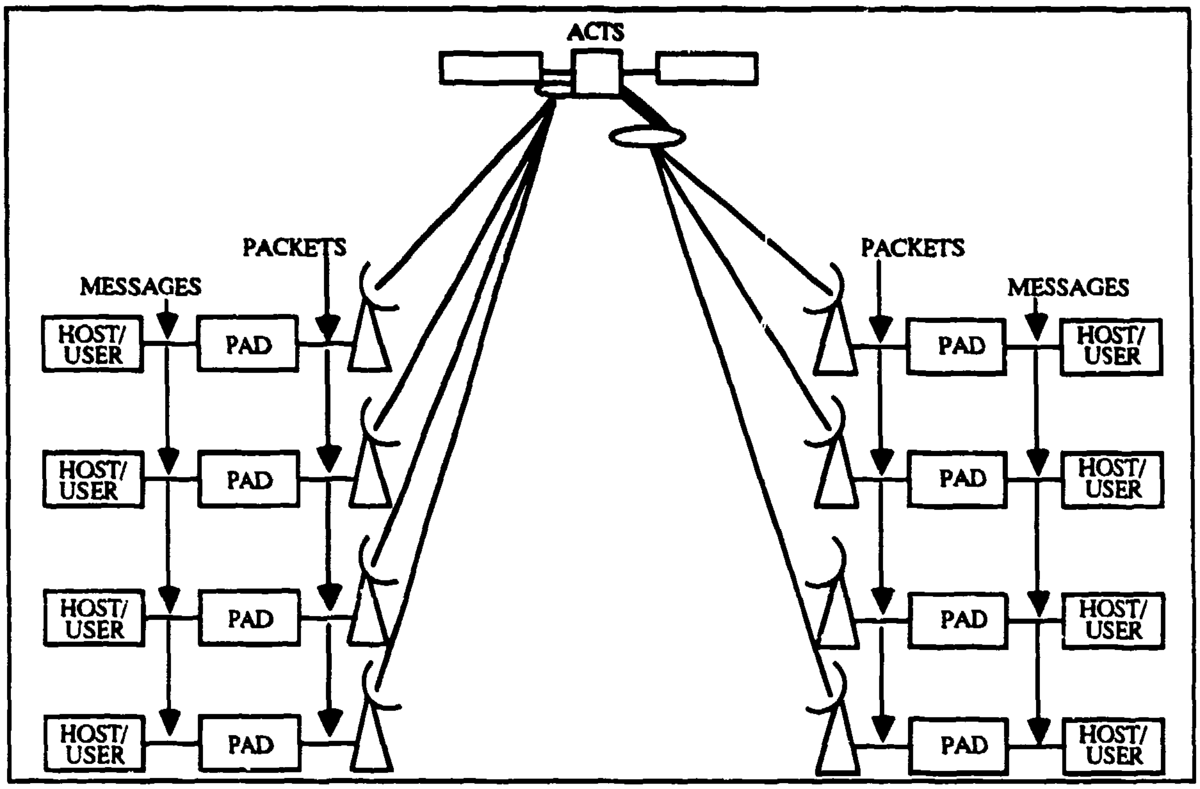


Figure 5.2 Ground Terminals Used at Every Host

A more effective use of the capabilities of the ACTS may lie between the two applications discussed above. This would entail using the ground terminals as a concentrator for a group of hosts. These hosts would be connected to the earth terminal and create a small network around the terminals. A switching capability at the ground terminal station would allow traffic to pass within the group without going to the satellite. This concept would take advantage of the clustered hosts and provide a more efficient use

of data rates possible within the ACTS system while paring down the number of ground terminals and circuits required. A traffic engineering analysis of the system and its requirements would be necessary to discuss quantities associated with this concept. That effort is beyond the scope of this thesis. The above concept is depicted in Figure 5.3.

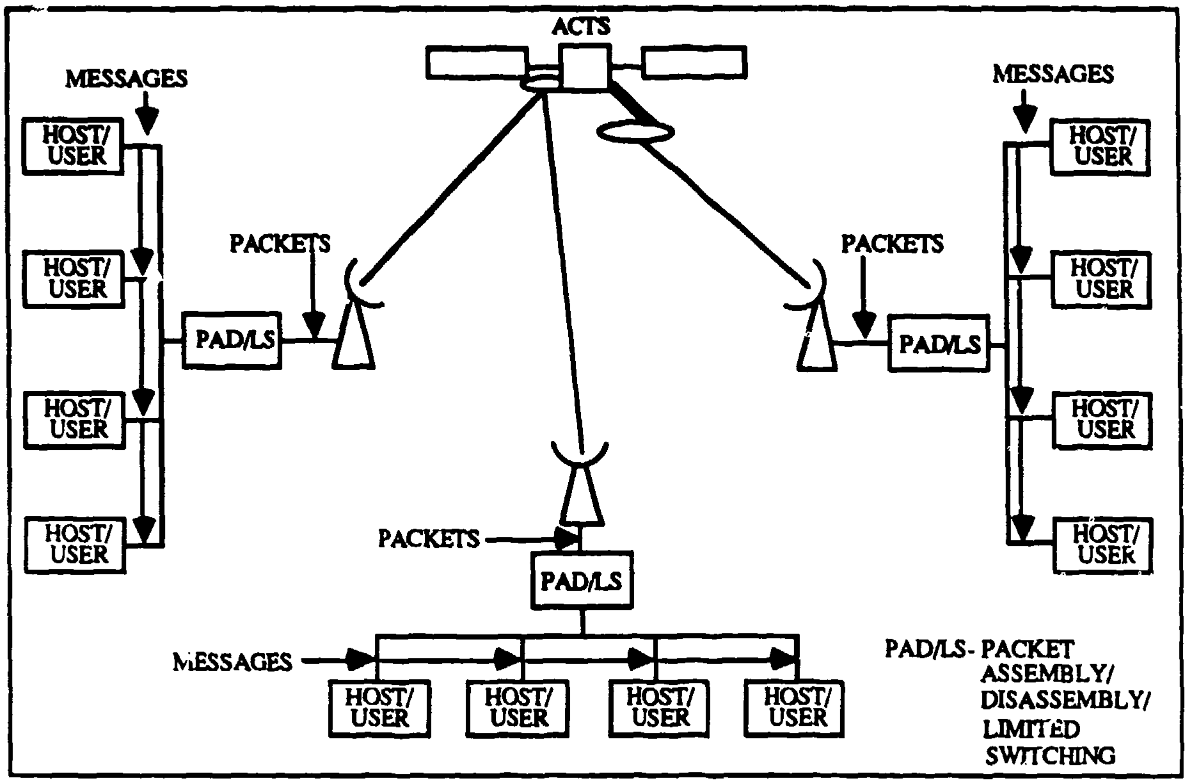


Figure 5.3 ACTS System Used with Clustered Hosts

As previously mentioned the above applications were discussed while overlooking some major shortcomings and advantages that are common among them. While these advantages and disadvantages do not in and of themselves make a case for using or not using the ACTS in the DDN, their consideration is essential in any further analysis. A brief discussion of these items will follow.

A major criterion in the operation of the DDN is its survivability capability. The ability of the system to suffer node or circuit failures and still be able to deliver traffic is a key requirement for this system. The ACTS system has

drawbacks and advantages in this area. Certainly any system like the DDN strives to eliminate any single point of failure that would cause a catastrophic system failure. The current DDN accomplishes this through many small switches throughout the network that have multiple interconnects to other switches. This provides a very robust system. An ACTS based system would have a failure point, the satellite, that could cause a failure of the system if the satellite was purposely disabled or suffered an equipment failure. A multiple satellite system would provide robustness in the system and perhaps eliminate a single point of failure for the system. However, whether the system could obtain the robustness of the terrestrial system is questionable. A feasible ACTS based system would certainly not be able to field a comparable number of switches. This would seem to create a major hindrance for a totally ACTS based system.

The ACTS system, however, provides some unique advantages in terms of survivability. The ability to place ground terminals at a host or node location and directly link that station to any other station significantly reduces the system's susceptibility to the destruction of transmission mediums. There are no cable or terrestrial radio systems to destroy that will interrupt the flow of traffic. The chokepoint in the system, the severity depending on the number of satellites, will be moved to a point in geosynchronous orbit thereby reducing the threat of terrestrial sabotage significantly.

A major advantage of the ACTS system is its ability to effectively use the communications capabilities of the system in conjunction with the requirements of the user. The demand access capability of the ACTS effectively allocates the required capacity of the system to the user requesting the service. In the preceding applications, the number of circuits leased was based on the number of nodes or hosts not on the anticipated traffic. The traffic level was accounted for in the data rate desired. This equated to a full time circuit between the satellite and the ground terminal. This is most probably a worst case situation. A more realistic situation would be that after an intensive traffic analysis study was accomplished some number of circuits would be leased. This number would probably be significantly less than a one to one ratio between circuit and node or host. These circuits can be more

correctly thought of as space on the satellite. All the stations within the corporation or agency that leased that space would have access to the satellite as they require it. The circuits are not allocated to specific terminals except as they are requested on a dynamic basis. As long as the number of stations trying to use the system does not exceed the leased amount, the system will pass the traffic. This capability provides a major advantage to the user in efficiently using transmission systems for the movement of his required data.

Another significant advantage of an ACTS based system is the capability for rapid reconfiguration of the network. The ground terminals with 1.8m antennas are mobile enough to move in and set up rapidly at new locations or if a failure occurs and reconstitution is required. This advantage parallels that provided by military satellite terminals used in mobile configurations. Long lead times for the establishment of dedicated circuits from the hosts to the nodes is the norm [Ref. 40: p. 214]. The following quote from the BBN study highlights the problem of quickly getting service.

> Voice-grade service is available almost everywhere with lead times of 90 days and up. T1 service is available in selected locations only, with lead times ranging from a few months to a year or even longer if new facilities need to be installed. [Ref. 40: p. 77]

Since most hosts are directly attached to the nodes, this does not present a critical issue. However, the changing of the system configuration by adding new hosts and switches requires long lead times to engineer the dedicated trunks or access lines. The ACTS terminal provides a rapid link into the system. This is a key advantage that has made satellites valuable in other communications applications.

The discussion in the preceding paragraphs has focused on general applications of the ACTS system to the DDN, and the discussion of some of the advantages and disadvantages associated with these applications. This discussion has not been exhaustive in its possibilities or required analysis. The intent has been to show the reader some basic applications and highlight advantages and disadvantages. The following topic was not discussed in this

section because the nature of the issue is so significant to the use of the ACTS that it warranted a separate discussion.

D. DDN COMMUNICATIONS SECURITY AND THE ACTS SYSTEM

In discussing the DDN in Chapter IV, it was clear that a very critical requirement of the DDN system was for the security of the traffic on the system. This is handled through bulk or link encryption and end-to-end encryption measures. The level of the encryption method, for example military grade certified encryption or commercial encryption, is dependent upon the network being discussed. However, the basic requirement is for the protection of all data traffic.

The ACTS system has a serious problem with the encryption requirements of the DDN. As stated, a basic feature of the DDN system is the use of link encryption to protect traffic between two nodes or a node and a host. This means that traffic leaving a node or host is encrypted just prior to entering the transmission medium, whether it has been previously encrypted or not. The encrypted traffic arrives at the distant node or host where it is decrypted. At this point, packets are either assembled into messages and delivered or the packets are routed to other nodes, in which case they again are encrypted for transmission.

The ACTS, in this case, is the packet switch or node. The ACTS functions on the premise of being able to take the uplink signal, break it out into the individual channels or data streams, and route them to their correct location. Therefore, the ACTS must be capable of decrypting the uplink signal to determine the packet routing. Since ACTS is essentially a commercially based effort for use in the civilian community, neither the experimental program nor the projected operational system have to this point incorporated encryption/decryption as part of the program. The incorporation of encryption/decryption devices on the satellite would increase the complexity and subsequently the cost of the system. Because the ACTS system is projected as a shared network where an agency or corporation would lease part of the capacity, the added difficulty of segregating the classified traffic from commercial traffic would be required.

Additionally, once the decrypted data is aboard the satellite, and prior to encryption for transmission, measures would have to be taken to prevent compromise of these signals.

The second facet of encryption in the DDN is end-to-end encryption. In this case, a message is encrypted prior to transmission from the user. The switches then break the already encrypted message into packets and transmits them into the system. The link encryption that precedes transmission doubles the encryption of the actual message traffic but only provides a single encryption of routing information. Therefore, if end-to-end encryption were used, the ACTS system could handle the traffic. The encrypted packets would be routed through the switch based upon the unencrypted address information on the packet. This method, while protecting the message data, does not guard against the analysis of addressing information.

The BBN Communications Corporation in its DDN report, *Future Network Technology Study: Final Report, Volume I: Findings and Recommendations* [Ref. 40], discusses the problem of encryption in a dynamic DDN system. Although the report was not discussing the ACTS system, but instead referring to a terrestrial system, the following remarks are applicable to the above discussion.

> Although we recommend the limited use of public packet-switching services as a substitute for dedicated lines in the access area, such services are not suitable for use as backbone trunks. The requirement to encrypt backbone trunk traffic even in the unclassified segment in order to thwart traffic flow analysis and to prevent denial-of-service attacks, makes use of these services impossible today.
>
> Even when end-to-end encryption devices for packet networks become available in the next few years, they will not provide protection against traffic flow analysis, since packet addresses and volumes cannot be hidden by these means. Encryption would be required in the public network backbone itself to provide this form of security, which is not a realistic alternative. [Ref. 40: p. 246]

These problems are just as serious in the ACTS network. Therefore, to take advantage of significant advances in communications technology and provide

a dynamic network poses a considerable problem if encryption is part of the system.

For the government to buy operational ACTS based satellites with encryption protection for use with government communications networks would be very expensive. Dr. Braham [Ref. 27] estimates that an ACTS system, consisting of three operational satellites, one as a ground spare, two satellite launch operations, ground stations (approximately ten thousand), support functions, and other required costs would cost between 1.5 and 2 billion dollars. This estimate would increase with the added cost of handling protected systems. This would be an expensive system and possibly not provide the redundancy and robustness desired in military systems.

This chapter has taken the previously described ACTS system and discussed its applications to the DDN. The discussion was not intended to make conclusive statements about the feasibility or infeasibility of the ACTS applications. The level of detail and analysis required to make any conclusive statements is beyond the scope of this effort. The intent was to provide the reader with information that may lead to areas of further analysis. The following chapter will discuss conclusions and areas for further study.

VI. CONCLUSIONS AND AREAS FOR FURTHER STUDY

A. CONCLUSIONS

As was discussed in the previous chapter, this thesis does not go into sufficient detail to support conclusive statements about the usefulness of the ACTS system in the DDN. To support such statements, a much greater analysis of all aspects of these systems and their operation together would have to be accomplished. Such analysis was beyond the scope of this effort. The intention was to provide, to a reader not familiar with the subject areas, a broad look at the emerging satellite technology and discuss the applicability of that technology to the DDN. To accomplish this, only broad levels of discussion and analysis were used to examine the applications. Therefore, the conclusions drawn from the exercise are general in nature, and should be subject to further analysis. The following comments are a result of the previous discussions.

As was previously stated, a key criterion for the DDN was system robustness. An ACTS based system, while providing comparable or better service characteristics, would have a difficult time establishing system robustness. This is in comparison to the DDN terrestrial system. The high cost of the ACTS system would make the procurement of numerous satellites for the support of one network, or of other government networks, not cost effective. The limited nodes in such a network would provide significant failure points even at geosynchronous orbit. Therefore, a network based solely on the ACTS would most probably not be feasible.

Additionally, the discussion of COMSEC considerations illustrated serious problems between the ACTS type system and the DDN. The projected ACTS systems could not protect DDN traffic and the cost of providing for cryptographic systems on the ACTS would most certainly significantly increase the price. Referring again to the quote from the BBN study on page 83, it was clear that the diversification of the DDN system into using the public network was a real consideration for increasing the survivability, redundancy, and service of the DDN. The COMSEC

drawbacks of the dynamic network were pointed out in the quote. A parallel was drawn between this quote and the COMSEC problems associated with an ACTS system. The current problem with COMSEC considerations should not prevent further consideration of the ACTS. The ACTS system provides a unique capability in communications that is expected to be heavily used by civilian corporations and possibly government agencies. The ACTS may provide an alternate path for the ACTS to enhance the redundancy, survivability, and capacity of the DDN. The use of the ACTS, in this manner, should be pursued with the COMSEC consideration as a key issue. Suggestions for further detailed analysis of this area to determine the ACTS applicability follow in the next section.

B. AREAS FOR FURTHER STUDY

The following are several areas that should be studied to further define the ACTS roles, if any, in the DDN or possibly other government networks:

1. An in depth examination of COMSEC problems surrounding the use of the ACTS based system with government protected systems and possible solutions.
2. An analysis of how, if given that COMSEC considerations were satisfied, would the DDN or other government systems make use of an in place ACTS-based network for enhancement.
3. An analysis addressing possible contingency uses of such a system, along the same lines as number 2 above.
4. An in depth analysis of DDN traffic and how much data rate capability would be required on the ACTS to handle a desired portion of the traffic load.
5. A cost analysis of the results of number 4 above in light of projected costs for fiber optic or other services.

APPENDIX
NASA PROOF OF CONCEPT TECHNOLOGIES

The following information is taken from *Switching Satellites* by Lovell and Cuccia [Ref. 8: p. 9]:

Fixed/Scanning Beam Antenna	Operational Model Gain	Tx	Rx
	18 Fixed Beams	56dB	53dB
	6 Scanning Beams	53dB	53dB
20x20 Trunking Switch Matrix	20x20 Port Cross Point Switch Switching Time 16 NS (Ford)		
Baseband Processor	Burst Rates 27.5-110 MBPS Capacity 6 CBPS		
30 GHz Low Noise Receiver	Noise Figure 5dB Bandwidth 2.5 GHz		
20 GH TWT	Multimode Power 7.5-75 WATTS Saturation Efficiency 25-40%		
20 GHz TWT Power Supply	Compatible with Hughes TWT		
30 & 20 GHz Latching Switches	At 20 GHz, 0.3 dB INS Loss At 30 GHz, 0.4 dB INS Loss		
20 GHz Impatt Amplifiers	Saturated Power - 25 Watts		
Low Cost CPS Ground Terminal Design Studies	Antenna/LNA/HPA Costs TDMA Versus FDMA System		
Transponder Simulation	Simulate ACTS Satcom System		
Low Cost Ground Terminal Antenna	Study Design/Costs of 2.5 Meter Nontracking Antenna 5 Meter Tracking Antenna		

30 GHz Solid State HPA	Saturated Power 25 Watts Bandwidth 500 MHz
Laser Intersatellite Links Studies	Transmitter Power 250 MW Data Rate 500 MBPS

LIST OF REFERENCES

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